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MOTORCYCLE RIDER SKILLS ASSESSMENT

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Abstract

To determine the differences between the control strategies of skilled and less-skilled riders as they control the lateral and longitudinal motion of a motorcycle, a study of motorcycle handling skills and their assessment was carried out. For the experiments, an instrumented motorcycle was developed which allowed the recording of the various rider/cycle control and response variables while skill tests were being conducted. Riders with a range of riding skills performed a standard skill test and an alternative skill test on the instrumented motorcycle. The experimental data were extensively examined and differences in the control behaviour over the range of riding skills were identified and quantified. A theoretical model was developed describing how less-skilled riders may control the lateral motion of their motorcycle.

KEYWORDS Motorcycle, riding, skill assessment, skill test, accidents, dynamics, handling, behaviour patterns, braking, steering, training, licensing, instrumentation.

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  (a) reports generated as a result of research done within the ORS are published in the OR series;
  (b) reports of research conducted by other organisations on behalf of the ORS are published in the CR series.

NOTE

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MOTORCYCLE RIDER SKILLS ASSESSMENT

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May, 1984

Project Sponsor:

Office of Road Safety
Department of Transport

SUMMARY

The high accident rate associated with inexperienced motorcycle riders has led to increasing interest by governments in rider training and licensing. Rider training is intended to develop, and licensing to test, knowledge and skills which will allow the motorcycle rider to safely negotiate most highway and traffic events. A prerequisite to effective training and licensing would seem to be an understanding of the characteristics of skilled motorcycle riding performances, the types of manoeuvres which challenge these skills, and control strategies employed by skilled riders which might be communicated to inexperienced riders. The study reported in this thesis has attempted to address these questions. To enable detailed observations of riding performances over a wide range of skill levels, an instrumented motorcycle was developed.

As part of the experimental program some of the steady state and dynamic handling characteristics of the experimental motorcycle - a Honda CB400T - were investigated. The results obtained provided assurance that the motorcycle was 'well behaved' over the range of speeds used in the skill tests. Furthermore, knowledge of the cycle's handling characteristics aided in interpretation of the collected data.

The main experiments comprised two skill tests. The first test was the Motorcycle Operator Skill Test (MOST), developed by the National Public Services Research Institute (1976) for the Motorcycle Safety Foundation in the United States. A sample of 59 volunteer riders with a wide range of riding experience was recruited to perform this test with the instrumented motorcycle. The 'penalty points' assigned in the MOST were used to subject the individual MOST exercises to an 'item analysis' to determine their consistency and relative power as discriminators of riding skill. It was found that for the motorcycle and sample of riders used, the 'best' skill discriminators were the emergency straight-path braking and obstacle turn exercises. Use of an unfamiliar motorcycle with a sensitive rear brake appeared to have

a detrimental effect on emergency braking in a curve: riders, on average, could not attain the required stopping distance in this task. Stopping distances achieved during straight-path emergency braking were considerably better. Analysis of the success rates for subjects in the left or right obstacle turn exercise indicated that riders are more likely to perform the manoeuvre successfully when manoeuvring to the left. This result is consistent with the findings in an overseas study in which the evasive capabilities of motorcycles and cars were compared. As riders only receive one attempt at this task in the MOST, those receiving a right-turn could be disadvantaged. Further, the performance check used for the emergency braking exercises in the MOST was found to be biased. Riders performing the test at too high or too low a speed are required to achieve significantly higher mean decelerations than riders travelling at the prescribed test speed. Also investigated were the characteristics of riders which contribute most to their score. It was found that being male and riding many kilometres in the average week were associated with a good score in the MOST. This result is largely consisted with other studies.

As a result of the experience with the MOST, an Alternative Skill Test (AST) was developed with the objective of providing a simpler test which would require a smaller test area, yet which would retain the best features of the MOST, while correcting some of its deficiencies. Further, the test was designed to incorporate elements of surprise and decision-making, in an attempt to make it more representative of in-traffic situations, and because it has been suggested in the accident literature that accident-involved riders often make inappropriate choices between steering and braking avoidance manoeuvres. A sample of 18 riders, chosen from the MOST group, was administered the AST using the instrumented motorcycle. It was found that the AST and the MOST led to a similar skill grading of the test subjects. Riders were able to achieve higher mean decelerations in the emergency braking tasks and succeeded more often in the obstacle turns in the AST than the MOST. However it is not possible to determine whether this was due to differences between the methodology of the tests, or whether there was a general improvement in subjects' riding ability during the less-than-two-month interval between tests. Reaction times in the AST were significantly longer than for the MOST, consistent with the greater uncertainty in the AST. Reaction times for the emergency braking task were found to be significantly longer than for the obstacle avoidance task for both the MOST and AST. This result indicates that it takes longer for a rider to initiate a change in the motion of a motorcycle when braking than when manoeuvring to avoid an obstacle. However, in the AST decision task, in which riders were required to brake and/or manoeuvre to avoid an obstacle, the riders' preference for braking appears to have been an appropriate choice in view of their success rates for the respective prescribed tasks.

The data collected with the instrumented motorcycle were extensively examined and revealed differences between the control behaviour of the skilled and less-skilled riders. In the emergency straight-path braking tasks the more skilled riders (as indicated by their overall MOST score) applied larger front and rear brake forces, had shorter reaction times, and were able to independently modulate their front and rear brake force inputs so that, as the motorcycle deceleration increased, the ratio of front to rear force increased in the manner required for optimum utilization of the available tyre/road friction. Average deceleration was used as a measure of rider braking skill. The highest decelerations were achieved by riders applying large front and rear brake forces and maintaining a constant front-to-rear brake lever force ratio. An examination of the time difference between the application of the front and rear brakes indicated that skilled riders applied the front brake first (in contradiction to a previous study where it was observed that the rear brake was applied first in most instances by two skilled riders). The data for the repeated prescribed braking trials in the AST showed no change in performance during the test, nor with an increased level of task difficulty. However, riders' braking skills appeared to have improved since they were administered the MOST. The improvement was apparently due to increased usage of the front brake.

Analysis of the obstacle-turn data revealed that the skilled riders had a shorter reaction time (consistent with the emergency braking result), achieved a larger steer angle during the turning phase of the manoeuvre, and applied a reverse steer angle for a shorter period of time than the less-skilled riders. Turn success was another measure of skill used, with results indicating that riders with a short reaction time were more likely to succeed in this task. The observation that there were no discernible differences between the control inputs of riders for successful and unsuccessful runs is consistent with the findings of another study.

The data for some of the less critical (easier) MOST exercises revealed that the skilled riders generated larger motion quantities, and more rapidly. This is consistent with observations made in other studies. In part they achieved this through the application of definite 'reverse steer' inputs at the appropriate times. There is also more inter-rider variability for the less-skilled riders in these tasks. In the obstacle turn exercise, however, there is as much variation in the control and response parameters between skilled riders as there is between riders classified as less-skilled, but less variation between successive runs of a skilled rider than a less-skilled one.

Further examination of the present study data, and data of another study, revealed a coupling between a rider's leaning motion and steering inputs, which appears to be stronger for the less-skilled riders. A mechanism was proposed to describe how riders utilize upper body leaning to control the lateral motion of a motorcycle. The mechanism has been used to develop a hypothesis on the stages of learning to control the lateral motion of the motorcycle: Novice riders appear to utilize upper body lean as their primary control input. Coupling of lean with steer torque by the proposed mechanism leads to appropriate, but slow, steering inputs. As skill develops these inputs are made more smoothly, but at the highest levels of skill the rider is able to apply lean and steer control inputs independently of each other. The mechanism was explored analytically and it was shown that by introducing lean-torque coupling into a rider/cycle model where lean is the primary control input, and the application of steer torque is via the proposed mechanism, the motorcycle's sensitivity to rider lean inputs is improved.

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CONTENTS

CHAPTER 1

INTRODUCTION

1.1 SIGNIFICANCE

Compared with automobile travel, on-street motorcycle riding is a relatively hazardous activity, and is especially so for inexperienced riders. The increasing cost of fuel has led in recent times to a sharp increase in the number of motorcycles on the road, and a consequent rise in the number of motorcycle accidents.

These circumstances, and the lack of generally-available training facilities for novice riders, have lead to increasing interest by governments in the provision of improved training and licensing programs. Two important requirements for such programs are: (a) a knowledge of the human performance parameters that differentiate between 'novice' and 'experienced' riders, which will allow specific goals for rider training and licensing to be defined (Waller et al., 1978); and (b) the ability to make economical assessments of safety-relevant rider skills.

1.2 AIMS

The aims of this study are:

(a) to identify characteristic patterns of rider/cycle behaviour associated with skilled and less-skilled performances related to task demands and motorcycle handling properties; and

(b) to develop methods of assessing rider skill level.

1.3 OVERVIEW OF REPORT

The literature is reviewed in Chapter 2 where skill and its acquisition are discussed in general terms, and characteristics of skilled performance are identified. The special skills required for the control of a motorcycle are then examined and characteristics of skilled and less-skilled behaviours in the operation of a motorcycle as revealed in past studies are summarized. The motorcycle accident studies have also been reviewed to determine whether relationships have been found between motorcycle accidents and factors such as riding experience and size of the motorcycle ridden. Other questions of importance for which answers are sought are: How do riders perform in an accident situation? Is their performance adequate?

The motorcycle itself, being the controlled object, is also examined. Unlike the automobile, which is inherently stable, the motorcycle requires constant control attention and thus represents a system which is more susceptible to roadway and aerodynamic disturbances. Studies which deal with cycle alone behaviour are reviewed, as are the analytical and experimental investigations where rider and cycle are treated as a combined interacting unit.

A portion of the work in this study required the development of an instrumented motorcycle capable of monitoring and recording rider control actions and motorcycle responses while the cycle is ridden during normal and emergency manoeuvres. As it was planned to recruit a large number of riders with a range of riding experience, and the possibility of a fall with the less-experienced riders during the emergency tasks was considered high, the instrumentation had to be reliable and robust. The instrumentation was used in experimental work, detailed in Chapter 3, to investigate some of the motorcycle's - a Honda CB400T - steady state and dynamic handling characteristics. These experiments provided assurance that the particular motorcycle used did not have any peculiar characteristics which may have affected the skill experiments.

For the main experiments the sample of riders were administered two skill tests. They were required to perform the tests on the instrumented motorcycle, thus allowing the important rider control and cycle response parameters to be recorded during the execution of each exercise and to be analysed, at a later date, in the laboratory.

The first test was the Motorcycle Operator Skill Test (MOST), developed by McPherson and McKnight (1976) for the Motorcycle Safety Foundation in the United States. This test is intended to provide an objective means for rating rider skills, with a minimum of (off motorcycle) instrumentation. The test has been widely investigated in North America and is being considered for introduction by several state governments in Australia (RoSTA in Victoria, TARU in New South Wales).

The performance of riders in the MOST is examined in some detail in Chapter 4, with the objective of finding which components of the test provide sensitive and discriminating measures of skill, and to uncover any deficiencies in the test. The characteristics of riders which contribute most to their score are also investigated.

As a result of the experience with the MOST, an Alternative Skill Test (AST) was developed, and is discussed in Chapter 5. The objective for the AST was to provide a simpler test, which could be carried out in a smaller area, which retained the best features of the MOST while correcting some deficiencies, and which introduced some elements of surprise and decision-making to the tasks. Results obtained from the AST are examined in a similar way to those from the MOST.

Data collected with the instrumented motorcycle during the conduct of the two tests is examined in detail in Chapter 6 to determine what distinguishes a skilled performance from a less-skilled performance. The analysis concentrates on the critical tasks of the two tests - the emergency straight-path braking and obstacle turn tasks. Some of the less critical exercises of the MOST are also examined as they highlight a number of differences between the riding techniques of the skilled and less-skilled riders.

The experimental evidence of Chapter 6, and of other researchers, suggested a strong coupling between the steering and upper-body lean inputs applied by riders, especially for the less skilled ones. This observation was used to develop a model for rider steering control which is investigated analytically in Chapter 7. Chapter 8 contains recommendations for further work and suggestions for rider training.

CHAPTER 2

LITERATURE REVIEW

2.1 SKILL

2.1.1 Skilled Performance

Skill can be defined as the practised ability in performing a task with accuracy, smoothness and repeatability. According to Krendel and McRuer (1960) "it is a composite measure of human proficiency based on task and man-centred criteria".

All skilled performance is mental in the sense that the requirement for perception, decision, knowledge and judgement exists. However a distinction is commonly drawn between mental skills and perceptual-motor skills. Perceptual-motor skills generally consist of responses to real objects in the spatial world, involving gross bodily skills (locomotion), manipulative skills (operation of controls) and perceptual skills (interpreting sensory information), whereas mental skills are generally associated with problem solving tasks (Welford, 1968). The present study is concerned primarily with perceptual-motor skills.

Skilled operation is goal-directed and is generally made-up of an organized and integrated sequence of activities (Fitts and Posner, 1967). In perceptual-motor skills these activities involve performing the appropriate co-ordinated motor responses for the task based on perceptual cues obtained from sources internal and external to the operator. Gibbs (1970) notes from other literature that skill is based largely on learned relations between the output motion of body members, and proprioceptive feedback which provides information about, and an awareness of, the state of one's muscles and joints without actually looking at them. An attribute of skilled performance is therefore the ability to produce appropriate responses to deal with a particular problem.

The degree of proficiency displayed by an operator in the performance of a task is reflected in the accuracy and uniformity of the component processes and/or in the overall execution of the task. In general, the more highly skilled operator performs more consistently and efficiently than the less-skilled operator (Welford, 1968).

2.1.2 The Acquisition and Development of Skill

The acquisition of any skill begins initially with a communicable program of instructions. The 'beginner' must, in general, try to understand the task and what it demands. Given the description of what he is supposed to do, the person still faces the major task of learning how to do it. In perceptual-motor skills this involves developing and co-ordinating muscular responses and sensory information intrinsic to the task at hand. The interposed elements that produce the skill are then obtained, in general, in a heuristic manner.

An essential characteristic of all skills is the requirement of continual practice. The initial attainment of reasonable competence is followed by a long period of further improvement during continued exercise of the skill. If the time taken by a task is split up into movement times, and times between movements, it is the latter which decrease more with practice (Welford, 1968).

The role of experience in skill acquisition is an important one. Experience, and therefore learning, are cumulative in the sense that each new situation is handled in terms of previous experience, and each new experience modifies what is carried to subsequent situations. In a new situation past experience generally has a positive effect and improves both speed and accuracy of the performance. Occasionally, however, the previous experience which is applied is irrelevant, or bears only a superficial resemblence to the necessary requirements, so that it hinders the 'learner' rather than helps in mastery of the task. As a result, the 'transfer effect' from previous learning is negative (Fitts and Posner, 1967; Welford, 1968). For example, driving a car requires the development of a variety of skills. The skills developed to cope with some traffic problems are directly transferable. By contrast, skills developed to control the lateral motion of a car differ quite substantially to those necessary to control the lateral motion of a motorcycle.

Early work on skill development was based essentially on Stimulus-Response (S-R) theory, in which, for a specific input signal, a stereo-typed, highly invariant output was produced. Based on this, the acquistion of skill was envisaged as being simply the formation of a stimulus-response chain - analogous to the connections made in a telephone exchange (Legge, 1970).

Inadequacies of the S-R approach, in relation to skill acquisition, were apparent when it was recognized that behaviour was also governed by motivation. One shortcoming of the S-R approach can be noted by realizing that within the human operator there are gross non-linearities, and input-output relations are also dependent on physiological and psychological factors (Gibbs, 1970). It is unlikely that a given input will produce a consistent, highly invariant output. The S-R approach could not provide the variability and adaptibility in dealing with changes in the environment.

The concept of feedback, which is extremely important in both skilled performance and in the acquisition of a skill (Fitts and Posner, 1967), and is used extensively in engineering control theory, provides the basis for a system with variability, adaptibility and self-equilibrating properties (Legge, 1970). Feedback provides the operator with information about the system responses (the motion of the controlled object), which includes system responses arising from previous operator inputs and environmental consequences of the response. With feedback the operator/controlled-object is sensitive to its own output and is less sensitive to disturbances.

A hypothesis for skill development, substantiated by experimental evidence from manual tracking, was proposed by Krendel and McRuer (1960). The 'Successive Organization of Perception' model presents a framework in which human-operator behaviour can be studied. According to Krendel and McRuer there are three levels of operator behaviour in skill development.

The lowest level in the hierarchy of control modes is control by 'compensation'. In this form of control the error, or difference between the desired and actual motion of (for example) a vehicle, is perceived and acted upon by the operator, whose corrective responses are produced to null the error. The operator attends only to the error, which is 'fed back', thus producing 'closed-loop' control.

'Pursuit' control is the next level in the hierarchy. In this type of control the operator uses knowledge of the path to be followed to improve performance by additional 'feedforward'. This knowledge is independent of the vehicle's trajectory, and the operator performs the control task in a closed-loop fashion.

The highest level of control is 'precognitive', which requires the operator to perform a repertoire of a practised sequence of control movements necessary for the desired manoeuvre. This sequence can be triggered by some stimulus in the visual or proprioceptive fields and the control movements are performed essentially without feedback in an 'open-loop' fashion.

Krendel and McRuer (1960) further hypothesized that a skilled operator will perform a task primarily in the precognitive control mode, whereas an unskilled operator will operate in a compensatory mode. As the unskilled operator acquires more skill in performing the task, his control progresses to pursuit, and eventually culminates in a precognitive mode of control. If, however, while operating in the precognitive mode the input information or task requirements change, in order to cope with the new situation the skilled operator regresses to the lower levels of control. The operator's task then is to make use of the new information to get back into the precognitive mode.

A similar model has been proposed by Fitts and Posner (1967). According to Fitts and Posner, as learning progresses the transition from one phase to another is gradual and not apparent. It is hypothesized that multiple subroutines, or short fixed sequences of operations, are combined within the human into an overall program - which is task dependent - to provide the unique character of each activity. As a consequence, learning skills involves a new integration and ordering of subroutines, of which many are transferred as a whole from other activities.

The initial phase, in Fitts' and Posner's proposed three level model, is referred to as the 'early' or 'cognitive' phase. During this phase of learning it is necessary to attend to cues, events and responses which will later become redundant. An initial repertoire of subroutines is selected from the available ones that were developed previously.

The 'intermediate' or 'associative' phase is the next level in the hierarchy. The appropriate subroutines are beginning to emerge, while errors based on inappropriate subroutines - wrong sequences of acts and reponses to wrong cues - are successively eliminated.

During the 'final' or 'autonomous' phase the component processes are becoming increasingly independent and are less susceptible to interference from other ongoing activities or external disturbances.

2.2 MOTORCYCLE RIDING SKILLS

2.2.1 Introduction

The rider/cycle system is a closely-coupled dynamic system with overall performance dependent upon both the handling characteristics of the motorcycle, and the rider's level of skill in controlling the motorcycle. The system is vulnerable to perceptual, aerodynamic and roadway disturbances. The rider must compensate for the unwanted effects resulting from such disturbances. The operation of a motorcycle, or any vehicle, requires the acquisition of a variety of skills. Some are more critically related to safety than others; their acquisition is crucial to performing the driving task successfully.

2.2.2 Motorcycle Task Analysis

Before skill assessment can be usefully performed, it is necessary to identify, in detail, the cues and responses associated with each skill.

An exhaustive inventory of performances, knowledges, and skills required in the operation of a motorcycle is provided by the "Motorcycle Task Analysis" (NPSRI, 1974). Each task listed in this comprehensive document is judged by what is referred to as a 'criticality rating'. The criticality rating is based on four 'criticality factors' which pertain to accident frequency and severity. High 'criticality' refers to a task which is essential to safe motorcycle operation and is highly associated with accident loss. A task with low 'criticality' is not highly associated with accident loss.

It should be noted that these 'criticality' values are products of human judgement and, to date, have not been validated against actual accident data. Validation has not been possible because data relating individual behaviours to accident loss are unavailable.

The "Motorcycle Task Analysis" serves as a guide in identifying skills and manoeuvres which are critical to safe riding. Tasks pertaining to basic control of a motorcycle having a criticality rating of between 5 and 9 (9 being the highest criticality rating), are as follows:

(1) Pre-operational inspection (check tyre inflation, actuate brake control(s), etc.).

(2) Post-starting engine (adjusts mirrors, practises with controls, etc.).

(3) Maintaining a stable vertical angle.

(4) Maintaining a stable lean angle.

(5) Maintaining a given direction.

(6) Changing direction.

(7) Normal speed reduction.

(8) Rapid speed reduction.

(9) Emergency speed reduction.

(10) Recovering from a rear wheel skid.

(11) Recovering from a front wheel skid.

(12) Correct action if a fall becomes inevitable.

Of the tasks listed, items (3) to (9) represent those which riders would be required to performed most frequently.

2.2.3 Skills for Motorcycle Operation

Riding a motorcycle demands the acquisition and development of the following types of skills (NPSRI, 1974; McKnight, McPherson and Johnson, 1977):

(i) Perceptual Skills - being able to interpret patterns of visual, auditory and proprioceptive and/or kinaesthetic stimuli. Two examples of perceptual skills are:

(a) the ability to determine the rate of closure with an concoming vehicle.

(b) the ability to judge the maximum speed at which a turn may be safely negotiated.

(ii) Manipulative skills - being able to perform complex and rapid manipulative sequences. The co-ordination of clutch and throttle involved in putting the motorcycle in motion, and changing direction, are two examples.

(iii) Mental Skills - being able to make inferences and deductions involved in problem solving or making decisions. An example is the ability to compute the motorcycle's operating range.

Furthermore, performance depends not only on the two divisions of perceptual and manipulative skills, but also on the relationship between them (Welford, 1968).

2.2.4 Handling Skills

Changing direction on a motorcycle is an example of a manoeuvre requiring skilled performance. Most riders are apparently unaware of the mechanism by which a turn from a straight to a curved path is achieved (Hurt, 1973). This process involves a fundamental handling property of the motorcycle. Hurt (1973) describes the steering inputs required to enter and recover from a turn as follows:

> "The path between straight line motion and the equilibrium turn requires an initial steering motion opposite that of the steady turn. To achieve the left turn, an initial steering displacement to the right causes the front wheel to track out to the right with the rear wheel following in track. As the desired angle of lean to the left is reached, the second steering displacement is made into the turn to match the true track of the equilibrium turn conditions. [See Figure 2.1.]
>
> In order for the vehicle to recover to a straight path, the vehicle must 'in-track' to reduce the lean angle and bring the vehicle upright. The recovery requires a steering input into the existing turn, causing the front wheel to track in with the rear wheel following in its track. As the vehicle reaches the upright condition, the second steering input is away from the previous turn toward the straight ahead path. [This process is depicted in Figure 2.2.]"

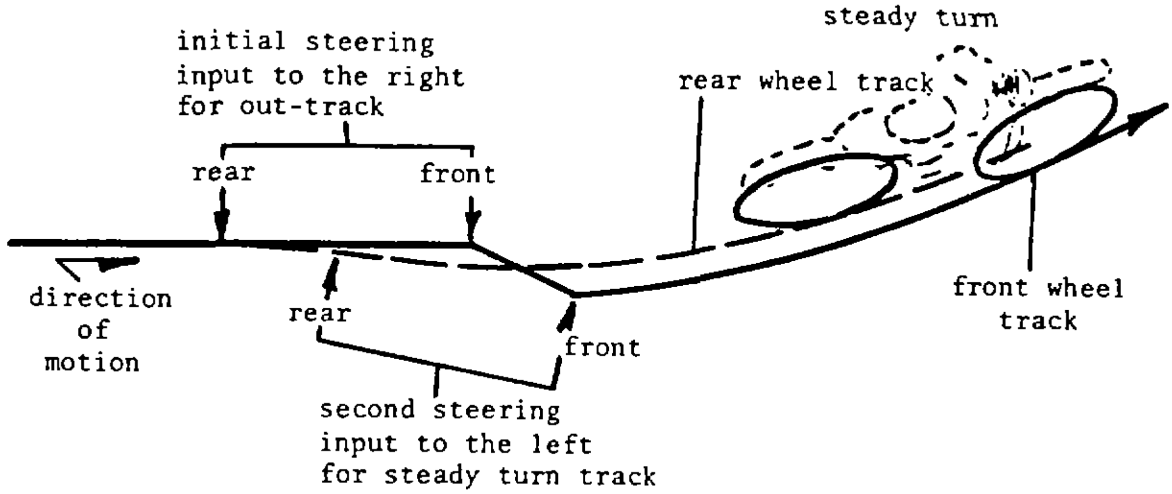

Figure 2.1 Out-track to enter left turn (Hurt, 1973).

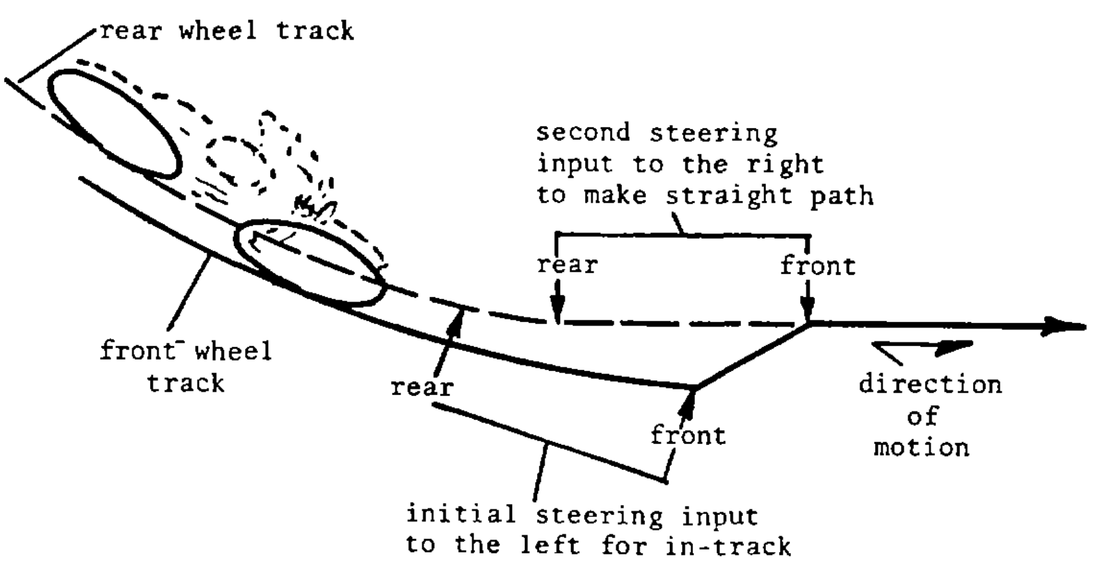

Figure 2.2 In-track to recover from left turn (Hurt, 1973).

In a hazardous situation the rider has little, if any, time to think. For riders having no knowledge of this handling characteristic, the conflict related to the initial steering input and turn direction can result in the rider turning into the hazard rather than away from it (Hurt, 1973). The most effective way to change direction on a motorcycle is by turning the steering assembly in a direction opposite to that of the intended turn. Where this 'reverse steer' strategy is not used, it has been suggested that the rider may even have to wait for the appropriate cycle position to develop from the normal roll oscillations of the motorcycles (McKnight and Fitzgerald, 1976) - clearly a less-effective way to initiate a turn.

A common misconception is that motorcycles are highly manoeuvrable, especially in comparison with an automobile. In reality, a motorcyclist is likely to be less capable of avoiding a collision in an emergency situation than an automobile driver (Goodrich, 1971; Watanabe and Yoshida 1973). This a direct consequence of the initial reverse-steering action. The appropriate initial steering action with an automobile is always in the desired direction of turn and the car begins to respond in that direction almost immediately. Typical evasive paths of an automobile and a motorcycle are illustrated in Figure 2.3.

Braking a motorcycle is a complex task requiring skilled operation. The general requirement is that the correct proportion of braking effort be applied, simultaneously, to the front and rear brakes. Deceleration of a motorcycle causes a 'weight transfer' to the front wheel. The braking effort should be distributed accordingly. The front brake typically provides - on a good dry surface - two-thirds of the total braking capacity of the motorcycle. Because a front-wheel skid is virtually impossible to control on a motorcycle, however, most riders do not utilize this capacity and overall braking performance is poor, in comparison with an automobile, as a result.

Most motorcycles have some degree of inherent stability resulting from trail, steering weight and gyroscopic effects of the engine and wheels. Although these effects aid the rider in stabilizing the

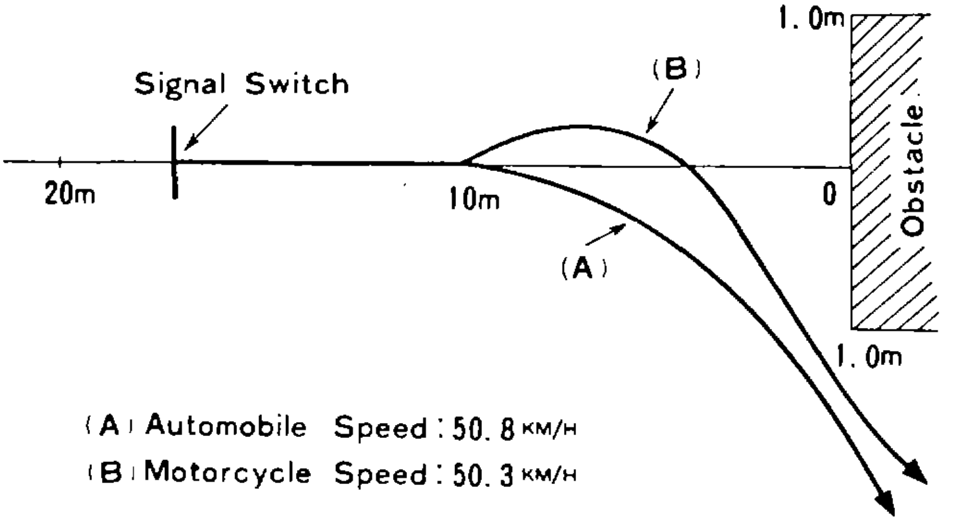

Figure 2.3 Evasive paths of an automobile and a motorcycle (Watanabe and Yoshida, 1973).

motorcycle, they are insufficient to maintain complete roll stability. Roll stability must be maintained by the rider during straight travel and while executing a transient manoeuvre or a steady turn. This is attained by turning the steering assembly slightly into the direction of excessive roll (typically requiring only a few degrees of steer angle). As the motorcycle returns to its vertical or equilibrium lean position, the steering is also returned to its position for the equilibrium condition. The steering requirements are identical to the steering actions for a turn, but are on a much smaller scale. The skilled rider performs this task continuously, providing the necessary compensatory actions without conscious thought (NPSRI, 1974).

Knowledge, acquisition and development of the aforementioned skills is essential for motorcycle riding.

2.2.5 Rider Behaviour Patterns Associated with Skilled and Less-Skilled Performances

There have been a number of experimental investigations aimed specifically at identifying skilled and less-skilled performance characteristics of motorcycle riders. It is of interest to review these studies as they may provide some answers to the question: how does a skilled performance differ from a less-skilled one?

Watanabe and Yoshida (1973) investigated the handling performance of three differently-sized motorcycles, and the effect of motorcycle size and rider skill on the emergency obstacle turn performance of a group of riders with a range of riding skills. Instrumentation was used to record the control and response parameters of the rider and cycle. There is no mention in their report of how the riders were graded in terms of skill. The results obtained experimentally were compared with those obtained using a computer simulation. It was found that the skilled riders produced larger steering inputs to obtain higher roll angular velocity and larger roll angles. The distance required by a less-skilled rider to manoeuvre around the obstacle was found to be 15 to 20% more than that required by skilled riders. Furthermore, motorcycle velocity had a larger effect on the steering operations of less-skilled riders than the skilled ones, in that the larger reverse-steer torques which must be generated at higher speeds could not be achieved by the less-skilled riders. Note that this was not because of any physical strength limitations.

Given the experimental findings, Watanabe and Yoshida (1973) attempted to simulate an unskilled rider with their computer model by, firstly, limiting the maximum roll angular velocity the rider could achieve and, secondly, slowing the rider's ability to shift body weight. These two variables, according to Watanabe and Yoshida, accounted for the differences in performance levels achieved by skilled and less-skilled riders. The results from their simulation are shown in Figure 2.4. Obviously the simulated less-skilled rider performs more poorly due to the imposed constraints. However, it would have been interesting to determine how each constraint contributed to overall performance. The example is however instructive in that it emphasizes the importance of at least one, if not both, of the two variables - maximum roll angular velocity and the rider's ability to shift body weight.

Further tests, which were conducted to investigate obstacle turn and braking performance, showed that braking distance increased in proportion to velocity squared whereas obstacle turn distance increased in direct proportion to velocity. The speed at which braking or an obstacle turn required the same distance was about 30 km/h. Above this speed it was considered that manoeuvring around the obstacle, as opposed to braking, would be a better evasive strategy. However, as noted by Watanabe and Yoshida, the emergency situation generally dictates the type of evasive action which can be taken.

Rice and Kunkel (1976) investigated rider behaviour as a function of skill level. Their work stemmed from an earlier study (Rice, Davis and Kunkel, 1976) which was directed at identifying objective performance parameters which can be used to discriminate between the accident avoidance capabilities of different motorcycles. In that study, difficulty was experienced in minimizing the effect of rider technique on the results and it was suggested that further work be

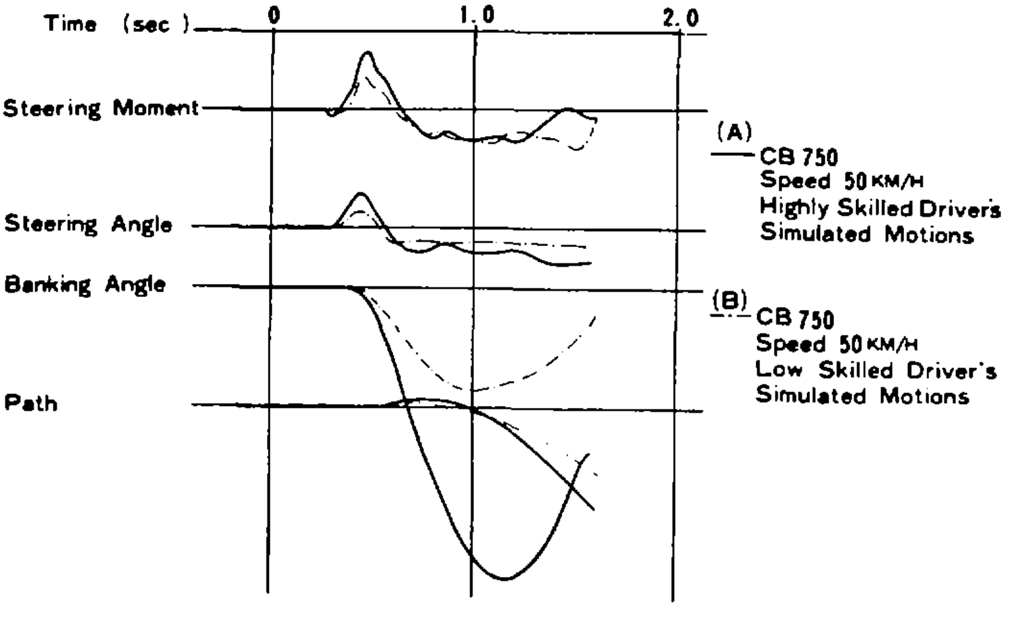

Figure 2.4 Simulated run to study the effect of differences in skill between riders (Watanabe and Yoshida, 1973).

conducted aimed specifically at identifying control strategy differences between skilled and less-skilled riders.

For their experiments, Rice and Kunkel (1976) required three different riders, classified by riding experience, to perform lane change manoeuvres. Choice of manoeuvre speed was left to the riders' discretion. According to Rice and Kunkel, for the most experienced rider an unsuccessful lane change attempt appeared to be the result of incorrect timing of the chosen action rather than variation in the control input. Hence they speculate:

> "...the experienced riders applied some type of preprogrammed control pattern with which they were either successful or not but which (because of the nature of the task) was not substantially varied after initiation of the manoeuvre."

This observation is consistent with the Successive Organization of Perception model proposed by McRuer and Krendel (1960), which was discussed in Section 2.1.2. According to the model the experienced riders operate mostly in a precognitive mode of control.

Rice and Kunkel also observed that the more experienced riders utilized upper body lean control more effectively than did the novice riders to cause the vehicle to roll in the proper direction more quickly than could be achieved using steer torque alone. Further, the novice rider employed more steering torque reversals than did the more experienced riders. This observation is consistent with that of Ellingstad, Hagen and Kimball (1970), that novice car-drivers (less than 10 hours of experience) make more steering inputs than experienced ones. This behaviour suggests, according to the McRuer and Krendel model, that a compensatory mode of control was active.

The influence of rider skill and experience on performance was further investigated by Rice (1978). Four riders of varying experience were used in a test program identical to the one used by Rice and Kunkel (1976). The more experienced rider was observed to produce larger initial steer torque and angle control inputs to achieve higher motorcycle motion quantities than did the novice rider, who also exhibited the greatest variability in control activities in successive runs.

The importance of proper usage of the front and rear brakes on a motorcycle was stressed in an earlier section. As part of an investigation of a procedure for evaluation of motorcycle brake systems, Ervin, MacAdam and Watanabe (1977) tried to identify, in a qualitative sense, the influence of rider skill on minimum stopping distance performance. Three riders classified by riding experience as professional, skilled and novice were required to stop as quickly as possible from two speeds (30 and 60 m.p.h.) using the following three braking techniques: both brakes, front brake only, and rear brake only. The following observations were made: the professional rider made greatest use of the front brake; repeatability in stopping distance and braking force attained by the professional rider exceeded that of the skilled and novice riders; the difference between the stopping distances achieved by the professional rider and the skilled and novice riders increased at higher test speeds; the skilled rider's stopping distances, although generally poorer than the novice's, were more consistent. The observation that the skilled rider displayed generally poorer stopping distance performance than the novice is somewhat surprising. It suggests that riding experience is a poor measure of a rider's braking skill.

Characteristics of skilled (as defined in these studies) and less-skilled behaviours gleaned from the studies examined can be summarized as follows:

(i) Skilled riders provide the motorcycle with larger steering inputs to obtain larger motion quantities than do less-skilled riders. As a consequence of this more 'aggressive' behaviour, the distance required to manoeuvre around an obstacle is substantially less for a skilled rider than for a less-skilled one.

(ii) There are more steering input reversals associated with a less-skilled performance than with a skilled one.

(iii) Skilled riders are able to utilize the control means of rider lean more effectively than less-skilled riders.

(iv) There is more inter-run variability for less-skilled riders.

(v) During braking a skilled rider makes more effective use of the front brake.

(vi) The difference in stopping distance performance between skilled and less-skilled riders increases with test speed.

(vii) Skilled riders perform transient manoeuvres by executing a learned sequence of actions essentially without feedback.

2.3 MOTORCYCLE ACCIDENTS

2.3.1 Introduction

Failure to acquire and develop skills in performing critical tasks and manoeuvres can be expected to increase the risks of being involved in a motorcycle accident. The literature has been reviewed to determine whether any relationships have in fact been found between accident occurrence and the following skill-related factors:

(a) Rider experience
(b) Rider age
(c) Motorcycle engine capacity
(d) Combined factors
(e) Rider training and licensing

Furthermore, the literature was also examined to try and identify the most common 'errors' made by accident involved riders.

2.3.2 Accident Related Factors

(a) Rider experience

Experience, both quantity (number of years of riding) and quality (type of riding), has been used, as was shown in the previous section, as a measure of the skill level of a rider. It can be said that an experienced rider is not necessarily a skilful rider since experience alone does not ensure the development of skills fundamental to safe riding (Hurt and DuPont, 1977). However, when compared with the experienced rider, the inexperienced rider is less likely to be familiar with both traffic and the motorcycle. For the less dexterous, inexperienced rider, performance of basic manipulative tasks in controlling the motorcycle may be stressful and reduce his or her capacity to attend to traffic and to develop longer-term path and speed control strategies.

Evidence presented in the literature indicates that inexperienced riders are in fact over-involved in road accidents. Scott and Jackson (1960) found experience to be an important factor in motorcycle accidents for young riders. Their data were obtained from police accident reports (5,563) and a mail survey of motorcycle owners (8,629). Analysis of the data showed that the 16 to 20 year old age group with less than six months experience had about twice the accident rate (based on exposure, i.e. distance ridden) of motorcycle owners of the same age group with more than six months experience. Data for this investigation were limited to persons who were owners of the machines at the time of the accident; data pertaining to borrowers were not examined.

Harano and Peck (1968) explored the relationship between factors associated with motorcycle accidents. Data collected on the motorcycle accident population, obtained from police accident reports, were compared with that from a random sample of non-accident registered motorcycle owners. Additional biographical and exposure data were obtained for each sample via a questionnaire. Furthermore, they wanted to determine if differences existed between motorcycle and non-motorcycle accidents. They concluded that:

> "....the most important finding of this study concerns the role of age and experience in motorcycle accidents ...[The] analysis suggest that a lack of skill or inexperience are more important factors in motorcycle accidents than in non-motorcycle accidents."

Their findings also suggest that factors related to vehicle familiarity may have an important bearing on motorcycle accidents.

The importance of familiarity with a particular motorcycle is reflected in the findings of Barry (1970). She investigated the role of inexperience by comparing reported crashes involving motorcycle owners with crashes involving borrowers. The crash data on 1230 motorcycle accidents were obtained from accident report forms and exposure data on 894 motorcycle owners were obtained through questionnaires. The study was based on the assumption that borrowers, in general, are less experienced and less familiar with the motorcycle than the owners. It was found that 22.8% of the reported motorcycle accidents involved borrowers, while they drove only 2% of the total annual mileage. The borrowers in two-vehicle crashes were travelling slower and were more frequently at fault than the owners. In single-vehicle crashes, the borrowers were more frequently reported to have crashed while attempting to execute a turn than the owner. A significantly higher proportion of night time crashes occurred with borrowers. It is important to note, as did Barry, that the average age of borrowers in crashes was significantly lower than the average age of owners. By comparing owners and borrowers having approximately the same age, a more accurate estimate of the relationship between inexperience and the high crash rate of borrowers would have been obtained.

Vaughan (1976), in a study of motorcycle crashes in N.S.W., found that "...inexperienced riders (here meaning riders who have held a licence for a short period, or who hold a learner permit) are involved in more crashes than they should be from the numbers of inexperienced riders in the population". Routine crash information collected by police officers was supplemented by additional information pertaining to rider characteristics, vehicle parameters (e.g. tyres) and pre-crash information. A total of 1506 reports formed the basic source of crash data. Control data, representing the population-at-risk, were obtained in a number of field surveys.

In the most recent and comprehensive study, Hurt et al. (1981) examined experience (in terms of months of riding), using not only total experience, but also experience on the observed (or accident-involved) motorcycle. Their work consisted of a detailed investigation of 900 motorcycle accidents with a highly-specialized multi-disciplinary research team. Information not normally available from police traffic accident reports was collected. On-scene, in-depth investigations were performed during 1976 and 1977. During the following two years, control data, representing the population-at-risk, were collected by interviewing 2310 riders and examining their motorcycles. In addition, 3600 police traffic accident reports were examined and compared with the accident and control data. The results indicate that inexperienced riders (0-6 months) are over-represented in motorcycle accidents and highly experienced riders (>48 months) are under-represented, the most significant measure being experience on the observed (or accident-involved) motorcycle. Furthermore, although half of the accident-involved riders had a total street riding experience of almost three years, their experience on the accident involved motorcycle was (on average) less than five months.

(b) Rider age

Kraus, Riggins, Drysdale and Franti (1973) carried out a study in which the injuries sustained by riders in motorcycle collisions, and factors pertaining to their occurrence, were documented. Data were obtained from police accident reports and hospital medical reports and compared with data collected from a randomly selected group of non-injured motorcyclists. Further data, not contained in the hospital and police reports such as riding history, frequency and type of motorcycle use, and whether or not the rider had received any training, were obtained from the injured motorcyclists and the comparison group via a self-administered questionnaire. A comparison of the age distribution of the injured and the comparison group riders shows that the highest relative accident incidence was for persons between 15 and 25 years of age. Also, 58% of all injured persons were between these ages. They concluded that persons in this age range were over-represented in motorcycle accidents.

In Australia, Johnston, Milne and Cameron (1976) investigated the interaction between age, experience and engine capacity and also took exposure, in terms of distance ridden, into account. Data for the accident involved riders were obtained from police reports. A random sample of owners of registered motorcycles formed the comparison group. A postal questionnaire was sent to both groups to obtain information not available from the mass data system. Table 2.1 was constructed from data of Johnston et al. (1976).

TABLE 2.1

ACCIDENT INVOLVEMENT AND RIDER AGE

Age	Usual riders of accident motorcycles		Usual riders of non-accident motorcycles	
	No.	%	No.	%
16 - 19	279	43.9	247	26.6
20 - 24	228	35.9	269	29.0
25 - 35	73	11.5	226	24.3
36 - 45	37	5.8	99	10.7
46 +	19	3.0	88	9.5
Totals	636	100.0	929	100.0

Source: Johnston, Milne and Cameron (1976).

The highest accident involvement was for persons in the 16-19 year age group. 79.8% of the accident involved riders are between 16 and 24 years of age. It can also be seen that persons in the 16-to-24 age group are overrepresented in motorcycle accidents when compared with the non-accident group. These results are consistent with those of Kraus et al. (1973) and those of Hurt et al. (1981), who found that riders in the 16-to-24 year age group are significantly over-represented in accidents.

(c) Motorcycle engine capacity

The relation between accidents and motorcycle engine capacity is an important one as it is generally believed that large capacity motorcycles are overinvolved in accidents when compared with small capacity machines (Hurt et al., 1981).

Scott and Jackson (1960) found in their study that "the more powerful the machine the higher the accident rate. This trend is extremely marked if the accident rate is computed per head (i.e. per rider): On this basis light motorcycles have 6 times the accident rate of mopeds, and the largest motorcycles have twice the rate of the light motorcycles. If the rates are worked out per mile the trend is still found but is much less marked." Vaughan (1976) also found that the involvement of larger capacity machines in accidents was disproportionate to their numbers on the road.

Kraus et al. (1973) reported that the involvement of motorcycles with more powerful engines (250 cc or more) in serious injury producing accidents was higher than would be expected based on their proportionate distribution in the comparison group. Smaller machines (less than 126 cc) were under-represented based on their distribution in the comparison group. Hurt et al. (1981) also found that higher injury severity is associated with large motorcycles. However, contrary to the popular belief that small capacity motorcycles are under-represented in motorcycle accidents, lightweight motorcycles (101-250 cc) were over-represented and cycles of capacity greater than 500cc were under-represented. According to Hurt et al., because the exposure data were gathered after the accident data (due to unexpected delays in funding) significant changes could have occurred in the population-at-risk between the two data sets. For example, they mention that the introduction of many new models of large motorcycles by most manufacturers may have caused an increase in the number of large motorcycles in the control sample.

(d) Combined factors

The data in the preceding sections have concentrated on single accident-related factors. It is important to examine the relationship between these factors.

Johnston et al. (1976) found that the highest accident probability was for young, inexperienced riders who ride large capacity machines. Accident probability was found to increase as exposure increases for motorcycles above 250 cc at all exposure levels. The importance of engine capacity in accident involvement was found to decrease as the age of the rider increased. The highest accident probability was for riders with less than two years experience who ride motorcycles above 250 cc more than 4000 miles (6400 km) per year. Vaughan (1976) was cautious in connecting age of rider, or experience, to engine capacity as reasons for crash involvement. He speculated that young inexperienced riders on high capacity machines may be risk takers, so that high crash involvement would be more a function of the riders' characteristics than the machine size. Vaughan concluded that "it was not possible to report whether 'inexperienced' riders on 'large' motorcycles were overrepresented in crashes".

(e) Rider training and licensing

Rider training and/or licensing schemes as a means of reducing motorcycle fatalities and injuries has been strongly recommended by investigators of motorcycle accidents (Harano and Peck, 1968; Hurt et al., 1981).

Preliminary evaluations of the effectiveness of three motorcycle licensing programs, and remedial skills training, were performed with a sample of 29,934 subjects by Anderson (1978) to demonstrate that improved testing procedures will result in a reduced accident rate for novice riders. The improved programs consisted of a series of countermeasures directed at raising the knowledge and skills of novice motorcyclists. Program A was the current standard California licensing program. It consisted of the present manual, knowledge test and skill test. Program B was the improved manual, knowledge and skill test with remedial training for persons who failed the skill test on their first attempt. Program C was similar to program B but without the remedial training for skill test failures.

The improved skill test, known as the Motorcycle Operator Skill Test (MOST), and the manual and knowledge test were those developed by McPherson and McKnight (1976).

Each applicant was assigned randomly by birthdate to one of three test sites. Driver violation and accident records of all applicants were monitored at different stages in the licensing process, even if the applicant did not complete the assigned program for the particular group. The evaluation of the program was based on motorcycle and automobile accidents and violation records for each group for the subsequent 6 month, 1 year and 2 year periods.

Analysis of the data showed that compared with program A, the improved programs showed a statistically significant reduction in motorcycle accident frequencies ranging from 16 to 22%. This was obtained for the full 2 year post-application period. The following two reasons are given by Anderson for the reduction in accident frequencies; (a) subjects in the improved programs had a lower exposure (opportunity to legally ride a motorcycle on public roads) than subjects in program A. The lower exposure of subjects in the improved programs derived from lower licensing and instruction permit issuance rates, and shorter criterion monitoring periods; (b) the improved programs in fact had a skill upgrading effect. Further analysis by Anderson, in an attempt to control for exposure, indicated that "exposure couldn't have accounted for all of the effectiveness of the improved programs". The analysis showed a reduction in motorcycle accident frequenices for programs B and C, when compared with program A, of, respectively, 1.8 and 15.7% for the full two year period. Neither of these was statistically significant. Furthermore, according to Anderson, the result for program B may be over-inflated because of a self-selection bias (subjects with greater accident and conviction likelihoods may have been discouraged from obtaining a motorcycle licence).

Hurt et al. (1981) found in their study that:

> "...while the greatest part of the population-at-risk is untrained, the trained motorcycle riders are significantly underrepresented in the accident data. The trained motorcycle rider is underrepresented in the accident data by an approximate factor of TWO."

Hurt et al. (1981) point out that the faults of chronolgy in their exposure data do not influence this result, as there was very little motorcycle training available during the accident and exposure data collection periods.

Although rider training and/or special licensing schemes are generally acknowledged as a means of reducing accident numbers, the results of several studies indicate otherwise. For example, Kraus et al. (1973) found that injured motorcyclists reported having received training in motorcycle use more often than did non-injured motorcyclists. The latter group was randomly selected from a list of motorcycle registrations. Note that the type of training received by these riders was not described in Kraus's report and it is therefore not known whether they had participated in recognized rider training courses, or whether they had been 'trained' by friends. In the Hurt et al. (1981) study, 92% of the accident involved riders, and 84.3% of the non-accident sample, had not received formal training; i.e. they had been self-taught or had received 'training' from friends or family.

Raymond and Tatum (1979) obtained similar results when evaluating the effectiveness of the RAC/ACU motorcycle training scheme in England. However their findings should be treated with caution because motorcyclists attending the training scheme attended on a voluntary basis. These riders formed the experimental group, and the control group was a sample from the motorcycling population who had not undertaken any formal training. Comparison of the accident rates of the two groups of motorcyclists formed the evaluation criterion. The data source consisted of self-reported accidents obtained from questionnaires and interviews. Analysis of the data showed that the difference between accident rates per rider in the two groups was not statistically significant. However, the control group had a statistically lower accident rate than did the riders who had received training when exposure, in terms of miles travelled, was controlled for, particularly during the first 5000 miles.

The effectiveness of the graded motorcycle licensing scheme in Western Australia was evaluated by Smith (1976). The scheme restricted persons from riding 'high powered' machines unless they showed satisfactory evidence of their skill to licensing authorities. Persons passing the road test on a motorcycle of capacity greater than 250 cc were issued with a 'K' class licence, on which no restrictions were placed. Persons passing the road test on a motorcycle of capacity less than 250 cc were issued with an 'L' class licence and were restricted to ride a motorcycle of engine capacity no greater than 250 cc. Analysis of the accident data, which were collected before and after the introduction of the scheme, showed that there was no statistically significant reduction in motorcycle accidents. Note that assessment of rider proficiency in controlling a large machine by licensing officers is subjective, and assessment will vary between officers.

2.3.3 Rider Performance

It is of interest to examine the behaviour of the accident involved rider where an evasive action was attempted, or where no other vehicle was involved, as it identifies areas where, had the rider been better prepared (perhaps through rider training), the incidents may have been avoided.

Henderson (1970) examined the N.S.W. police accident reports for all fatal motorcycle crashes during 1969 and for the first four months of 1970 and found that single vehicle crashes accounted for 32% of all fatalities. In virtually all of these cases, from the evidence available, the rider appeared simply to have lost control of the machine. Harano and Peck (1968) found statistically significant differences between the type of vehicle involved in accidents, with motorcycles having more accidents on curved roads. Foldvary (1972) cites evidence from an overseas study that, in two-thirds of a total sample of 62 single vehicle accidents the rider lost control over the machine while negotiating a curve in the road. Of these, 44% were under the influence of alcohol and 23% were driving with a speed above the set limit. Of the 935 motorcycle accidents reported to the North Carolina Department of Motor Vehicles in 1968, Waller (1972) found that 33% involved no other vehicle. 28% of these occurred whilst the motorcyclist was negotiating a curved section of the roadway. Hurt et al. (1981) found that in 21.6% of the loss-of-control accidents the rider ran wide in a turn. According to Hurt, excessive speed or undercornering were typical errors made by the rider.

There is further evidence (Department of Health, 1976; Watson and Lander, 1974) indicating that, excluding the effect of alcohol, loss of control while negotiating a bend in the roadway, or while turning a corner, is not an uncommon occurrence in single-vehicle motorcycle accidents. Whether loss of control during cornering is due to poorly developed handling skills, or simply inattention on the rider's part remains an open question. Other factors such as the dynamic characteristics of the motorcycle cannot be ignored. It is shown in Section 2.4.2 that during cornering the dynamic characteristics of motorcycles are somewhat different to the straight travel characteristics, and there exists the possibility of an instability occurring. This, in conjunction with a rider's lack of skill and/or inattention, provides one explanation for the occurrence of accidents during cornering.

As was discussed earlier, braking a motorcycle is a complex task requiring the application of the correct proportion of braking effort, simultaneously, to the front and rear brakes. This operation is of particular concern, even to the experienced rider, since a front wheel lock presents a situation in which directional control is lost. Watson and Lander (1973) found that in 7 of the accidents studied (6%) the motorcyclist lost control during braking. Hurt et al. (1981) found that the braking behaviour of accident involved riders was poor:

> "...both brakes were used in only 17.0% of the accidents (and many times not used well). The most common action was to use the rear brake only (18.5%) or rear brake and swerve (11.7%). This failure to use the front brake is a critical element in collision avoidance because proper use of the front brake would have avoided many of the collisions or greatly reduced the severity."

Choosing the correct evasive action, according to Hurt et al. (1981), is also a problem. For example, an evasive action of braking was attempted by 35.8% of the total sample; 8.2% attempted to swerve, and 31.4% did nothing. The choice of evasive action was considered correct for only 45.7% of the riders who attempted to brake and 33.8% of those who swerved.

For 7 of the 31 cases attended by multidisciplinary accident investigation teams, for which rider and cycle information was available in Herbert and Humphrey's (1978) study, an appropriate or unattempted collision avoidance manoeuvre was a contributing factor: riders swerved to avoid a collision when it would have been better to brake, and vice versa.

2.3.4 Summary and Conclusions

Of the accident studies reviewed, and the accident related variables considered, the following relationships were found to exist:

(i) Lack of experience, in terms of total years of riding and years on a particular motorcycle, is associated with accidents. Riders with little experience are overinvolved in motorcycle accidents. Furthermore, riding/driving experience appears to be a more important factor in motorcycle accidents than in non-motorcycle accidents.

(ii) Riders of age less than about 25 years, are overinvolved in motorcycle accidents.

(iii) Although there is a fair amount of evidence suggesting that large motorcycles are overinvolved in accidents, the results of the most recent and most detailed study indicates the opposite, namely that small capacity motorcycles are overinvolved in accidents. However, faults in the methodology for this study may account for this result.

(iv) There is some evidence to suggest that rider training and/or licensing schemes are effective in reducing the number of motorcycle accidents, however, the findings are not conclusive and should be interpreted carefully. Although there is evidence to the contrary, the experimental methodolgy of these studies requires that their conclusions be interpreted with caution.

In relation to performance of the accident-involved rider where no other vehicle was involved, and where the effect of alcohol was not a contributing factor, or where the rider attempted an evasive action, the following conclusions can be drawn:

(i) The accident-involved riders do not make full use of the braking capabilities of the motorcycle; typically only using the rear brake, or making ineffective use of the front brake.

(ii) Choice of the correct evasive action, i.e. braking and/or manoeuvring to avoid an obstacle, appears to be a problem with the accident-involved rider.

(iii) Loss of control while negotiating a curved section of the roadway is a common occurrence in single-vehicle motorcycle accidents.

2.4 MOTORCYCLE DYNAMICS

2.4.1 Introduction

The motorcycle is an integral part of the rider/cycle system and it governs the type of control activity required from the rider. Any dynamic characteristics, such as easily excited or unstable modes of motion, which may impose an extra workload on the rider, or cause control difficulties, will in general adversely affect the ease and precision with which the cycle can be controlled. In some instances - if these problems are serious enough - they may lead to loss of control. It is therefore of prime importance to have a knowledge of the dynamics and response characteristics of the motorcycle.

2.4.2 Motorcycle-Alone Dynamics

The studies discussed in this section are primarily concerned with examining the stability characteristics of the motorcycle where motion of the rider relative to the bike, and the behaviour of the rider as a controller, have been neglected. The rider in these studies is generally represented as a rigid extension of the rear assembly.

The earliest detailed study of the stability of a single-track vehicle appears to be Whipple's (1899). It is of interest to present some of Whipple's findings as they are still relevant today. Whipple developed equations of motion for a bicycle in linearized form; that is, small oscillations about steady motion were considered. The bicycle was represented as consisting of two frames hinged together at the steering axis. The wheels were modelled as rigid circular discs making point contact with the ground and gyroscopic effects due to their rotation were considered. Parameters were measured for an example bicycle and used as input to the equations to explore the cycle's behaviour. Four critical velocities were identified, of which only two pertain to the uncontrolled bike. The highest critical velocity represents a speed above which the cycle has a tendency to slowly fallover; the lower one a speed below which "the oscillation of the front-frame about the [steering] head tends to increase in amplitude". Between these two speeds the motion of the uncontrolled cycle is stable. According to Whipple the motion above the highest critical speed "may be rendered stable by a rider who turns the front wheel towards the side on which he is falling, or who moves his body away from that side".

Following Whipple's study other early treatises on single-track vehicle stability appeared. However, these were not as detailed (Pearsall, 1922) and, as in Whipple's analysis, tyre mechanics were ignored. Further, in one study (Bower, 1915), the effect of an inclined steering axis was neglected. More recent efforts made contributions to knowledge in this area (e.g. Kondo et al., 1963); however, tyre behaviour was again not properly represented.

In a landmark study Sharp (1971) examined the effect of different tyre models and cycle parameter variations. His detailed and comprehensive model allowed for degrees of freedom in lateral motion, yaw, roll and steer. Forward speed was constant. The motorcycle was modelled as consisting of two rigid frames joined at the steering axis, with freedom of the front frame to steer relative to the rear one. Gyroscopic effects of the front and rear wheels and engine were considered. Only small perturbations from straight-line running were considered.

The model was developed in both 'free control' and 'fixed control'. In vehicle handling terminology 'free control' is when the rider exercises control by way of steering force. When control is exercised by steering angle, it is referred to as 'fixed control'. The motorcycle dynamic responses are more compatible with rider capabilities when the rider exercises control by way of steering force rather than steering angle. If the rider were to employ a fixed control strategy, he would have to generate far more complex 'compensation' to stabilize the closed-loop rider/cycle system, and he would be hampered by a lack of feedback information due to the very small steering angles typically required (Weir, 1972). Sharp (1971) concluded that the 'fixed control' characteristics of the motorcycle are unimportant.

The equations of motion for the cycle were developed for three different tyre models. The most sophisticated tyre model incorporated sideslip freedom, an occurrence related to tyre flexibility which causes the direction in which the wheel rolls in a turn to diverge from the direction in which it is pointed, and tyre relaxation, which represents the time delay between the steering of the pneumatic-tyred wheel and the building up of the side force towards a steady state value. This tyre model was compared with a tyre model with no sideslip freedom and another with sideslip freedom but with no lag time.

Analysis with the most sophisticated tyre model yielded three physically significant modes of motion. These were referred to by Sharp as the 'capsize', 'weave' and 'wobble' modes. Other modes of motion were considered to be physically insignificant, either because they were heavily damped, or because they could not be excited to amplitudes comparable with the amplitudes of the capsize, weave and wobble modes. Weir (1972), and Eaton and Segel (1973) have substantiated Sharp's equation of motion independently and obtained the same characteristic modes. The important features of the modes are as follows:

• Capsize Mode

This mode is aperiodic (non-oscillatory) and involves roll of the motorcycle. It can be either stable or unstable. If unstable then roll divergence is slow (a time to double amplitude in the range of 5 to 10 seconds). The stability of the capsize mode is speed dependent; typically this mode is stable for a range of low speeds only.

• Weave Mode

This is an oscillatory mode and involves combined steering, yawing and rolling - the cycle undergoing periodic lateral excursions. Its natural frequency is speed dependent, ranging from about 1 Hz at low speeds to about 3 Hz at higher speeds. The oscillation is well damped at moderate speeds and only lightly damped at low and high speeds. The weave mode is unstable at very low and high speeds.

• Wobble Mode

Wobble is characterized by an oscillatory motion of the front fork assembly about its axis of rotation (typically in the range 6 to 10 Hz, relatively independent of speed). It is unstable at very high speeds. The oscillatory characteristic of the front fork is influenced by steering damping and hence by the way the rider grips, pulls or pushes the handlebar.

Eaton and Segel (1973) modified Sharp's equations of motion to include tyre self-aligning torques and overturning moments resulting from slip and inclination angle. The results obtained analytically were compared with experimental results obtained with an instrumented motorcycle. To minimize rider effects, the rider's upper-body was braced. In the analytical investigation the following four tyre models were used:

(1) Side forces caused by slip and wheel inclination angle; no moments other than self-aligning torque as a function of slip angle.

(2) Same as (1), with self-aligning and overturning moment dependence on inclination angle added.

(3) Same as (1), with self-aligning moment dependence on inclination angle added.

(4) Same as (1), with overturning moment dependence on inclination angle added.

The results of the theoretical investigation showing the effects of the tyre models can best be shown on a Root-Locus plot. This is a locus of the roots (solutions) to the characteristic equation, plotted as a function of a parameter (in this case forward speed of the motorcycle). It gives an instantaneous view of that parameter's effect on the behaviour of the system in general, and in particular information on stability. It is plotted on a complex plane with real and imaginary axes. For the purposes presented here it is sufficient to state the following: The real part of the root indicates stability of the system. If the real part is positive the system response is exponentially divergent. If negative, the response is exponentially convergent. If the root has an imaginary part then, as well as being either convergent, neutrally stable - real part equal to zero - or divergent, the system response will be oscillatory.

Figure 2.5, taken from Eaton and Segel (1973), illustrates the behaviour of the three significant modes of motion with vehicle forward speed as a parameter. As can be seen, both oscillatory modes become less well damped as speed inreases and the wobble mode is unstable at 100 m.p.h. (160 km/h). The capsize mode, as discussed previously, is aperiodic, becoming unstable at higher speeds.

Figures 2.6 and 2.7 show the effect of tyre model on the weave and capsize mode roots respectively. As noted by Eaton and Segel from Figure 2.7, the overturning moment tends to destabilize the capsize mode whereas aligning torque has the opposite effect. For the tyre studied, these effects tend to cancel each other if incorporated simultaneously. Tyre model choice only influences weave mode roots below 20 m.p.h. (32 km/h).

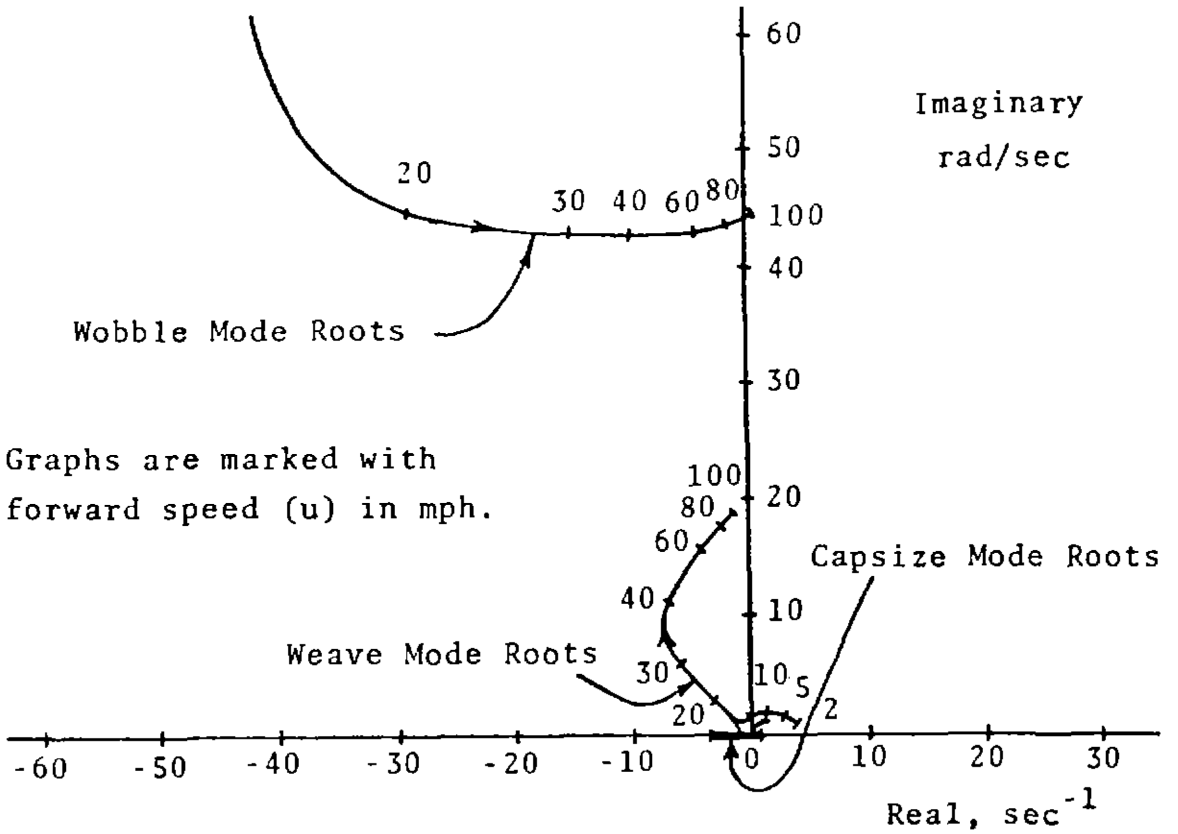

Figure 2.5 Roots loci of the characteristic modes (Eaton and Segel, 1973).

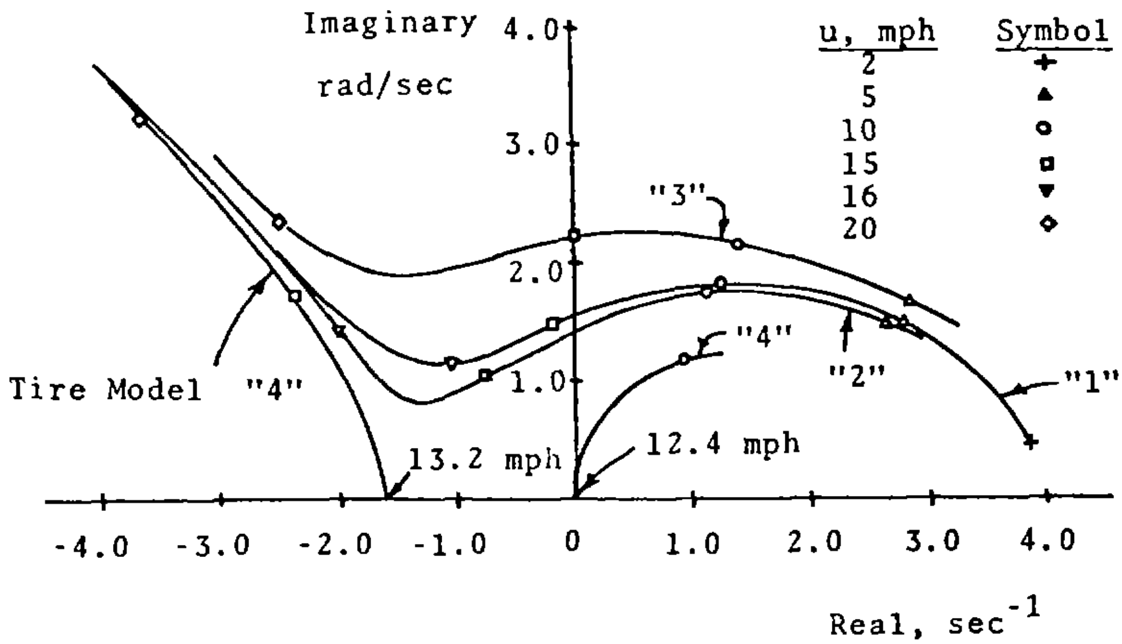

Figure 2.6 Weave mode roots for different tyre models and low forward speed (Eaton and Segel, 1973).

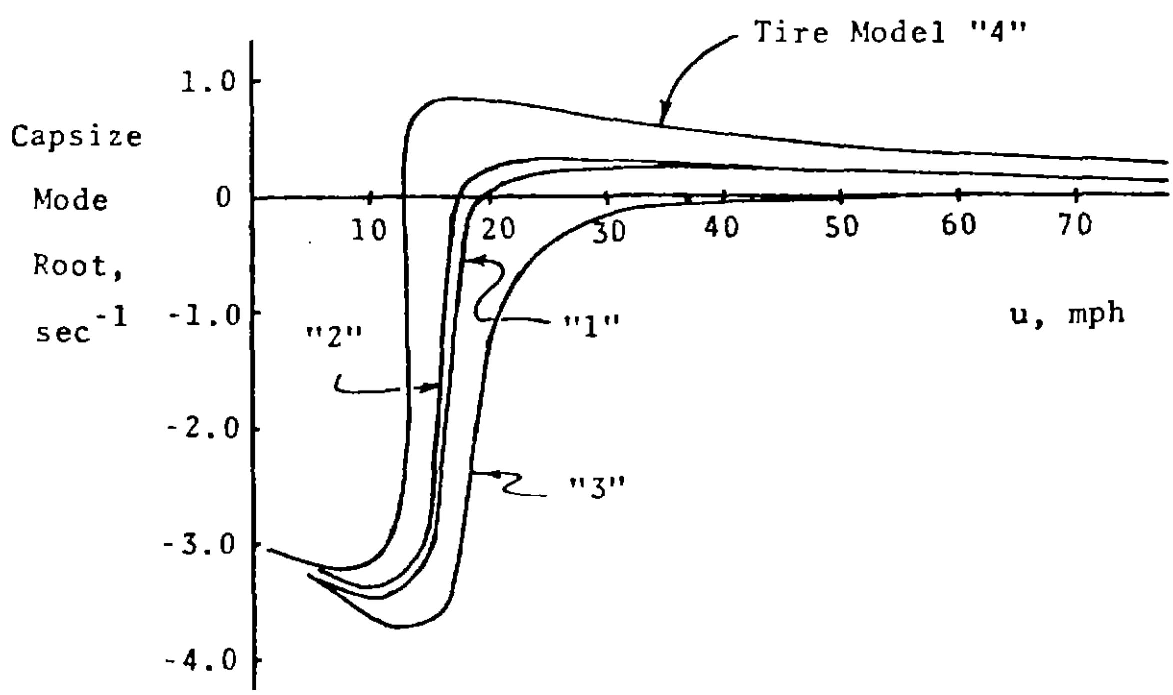

Figure 2.7 Capsize mode roots (Eaton and Segel, 1973).

Comparing theoretical and experimental results Eaton and Segel found, contrary to their theoretical results, that it was not possible to experimentally locate an operating range which was completely stable. Further, the low frequency weave mode could not be excited experimentally and vehicle stability improved as speed was increased. The difference between theory and experiment was attributed to the tyre model used and they concluded, as have Segel and Wilson (1975), that a more realistic tyre model should be developed.

Other studies using improved tyre models have been performed (Sharp and Jones, 1977) and the effects of aerodynamic forces included (Verma, 1978). These modifications caused only small changes in the frequency and damping characteristics of the capsize and weave modes. The largest effect was to decrease the damping of the wobble mode to values in closer agreement with experimental results.

In the studies discussed thus far (with the exception of Verma's (1978)), the cycle frame has been represented as a perfectly rigid one. It is of interest to examine how frame flexibility influences the predicted natural mode charateristics. Torsional flexibility in the rear swing arm has been shown to reduce the damping of the weave mode at medium and high speeds (Sharp, 1974). However, when flexibilities are introduced into the motorcycle frame, front fork and rear swing arm simultaneuosly, only a small change in the predicted behaviour of the capsize and weave modes occurs. The largest effect is to lower the frequency of the wobble mode and to change its damping (Verma, Scott and Segel, 1980; Sharp and Alstead, 1980).

As motorcycles do not always travel at a constant speed, or in a straight line, it is natural to enquire as to what effect these two parameters have on stability. Sharp (1976a) found, for the example motorcycle studied, that acceleration improved the stability of the capsize mode while deceleration made it worse; the effect was particularly pronounced near to 10 m/s (36 km/h). Further, it was found that under some circumstances acceleration can reduce the weave mode damping together with an increase in wobble damping. These results are largely consistent with those of Goel (1983).

When modelling the motorcycle, researchers often ignore suspension movements, their characteristics (stiffness and damping properties), and hence the corresponding characteristic modes of motion of the motorcycle in its plane of symmetry. The possibility of interaction between the in-plane bounce and pitch modes of the motorcycle was considered by Sharp (1976b). He found, for the example motorcycle studied, that the frequency of a mode which is almost purely pitch approaches that of the weave mode frequency. Clearly, if the damping of both of these modes is light, interaction between them would be expected to occur. During cornering there exists a likelihood of a combined weave/pitch or weave/bounce mode becoming unstable (Sharp, 1976b; Pacejka and Koenen, 1979). Experimental evidence indicates that the damping of the 'weave' oscillation during cornering decreases (Weir et al., 1978; Weir and Zellner, 1979). This behaviour appears to be most pronounced for speeds above about 100 km/h when the in-plane pitch mode frequency and lateral weave mode frequency coincide (Jennings, 1974; Weir et al., 1978). The coupling between these modes, and the speed at which it occurs, depends on a number of variables of which the suspension parameters (Jennings, 1974), and how the motorcycle is loaded (e.g. presence of a pillion passenger), are important ones (Weir et al., 1978). The paucity of data related to this phenomenon, and the lack of guidelines instructing users on how to safely load their cycles, suggests this to be an area where further investigations should be made.

2.4.3 Steady Turn Characteristics

Studies conducted to specifically examine motorcycle steady turn characteristics, to identify desirable steady state handling characteristics are reviewed in this section.

The importance of steer torque as a control variable was stressed by Sharp (1971). Under steady turn conditions the direction of the steer torque which a rider must apply to maintain the turn, when the rider's upper-body remains in the plane of symmetry of the motorcycle, has been found to change as the speed of the motorcycle increases (Sharp, 1971; Ellis and Hayhoe, 1973; Rice, 1974; Rice et al., 1976; Fu, 1977; Weir et al., 1978; Watanabe and Segel, 1980). For low speeds the steering assembly has a tendency to turn further into the direction of the turn being negotiated and the rider must - in order to maintain steady turn conditions - apply a torque opposite in sense to the turn being negotiated. It appears that riders are not sensitive to the polarity of the torque and the important rider activity seems to be maintaining stability about some steady state condition (Sharp, 1971; Watanabe and Segel, 1980). The speed at which the applied steer torque is zero, and above which it is in the same direction as the turn, is referred to as the 'inversion', or 'transition' speed and, according to Weir et al. (1978), it coincides with the speed at which the capsize mode becomes unstable. As discussed in the previous section, the instability is relatively mild and requires some roll stabilization by the rider. Rice (1974) suggests that the inversion speed for a bicycle "identifies operating conditions for which a heavy burden is placed on the rider for maintaining system stability". The author disagrees with this view and sees no reason why the cycle behaviour at this speed should differ significantly from its behaviour at a speed slightly above the inversion speed.

For two-track vehicles, the characteristics of great importance in normal driving appear to be the steady state response gains (e.g. yaw rate to steer angle gain, lateral acceleration to steer torque gain), the lag time between steering inputs and vehicle responses (e.g. yaw rate response time), and the stability or damping of the directional response. All of these response characteristics are influenced by the 'stability factor' or 'understeer/oversteer gradient' (Good, 1977), which determines the variation of steady state response gain with speed. The stability factor is considered to be the most important measure in defining a two-track vehicle's directional characteristics (McRuer and Klein, 1974).

Weir, Zellner and Teper (1978) attempted to identify correspondingly important response characteristics for motorcycles. The effects of a number of vehicle characteristics on the subjective opinion of one skilled test rider performing lane change manoeuvres was investigated. For example, Figure 2.8 shows the effect of stability factor on rider ratings. The data suggest that neutral to modest oversteer is preferred, in sharp contrast to automobiles, for which a degree of understeer is required. However, Weir et al. describe their results as, at best, preliminary and note that the relevance of stability factor to handling quality has yet to be determined for two-wheelers. Watanabe and Segel (1980) maintain that understeer/oversteer "is not a significant measure of the directional control quality of a motorcycle".

It is of interest to examine the composition of the understeer/oversteer gradient for a 'linear' motorcycle, as it reveals how the 'ingredients' of this measure differ from the two-track vehicle ones. Several analytical investigations (Krauter, 1973; Fu, 1977; Watanabe and Segel, 1980) have shown that, in contrast to the results for two-track vehicles, the stability factor of a motorcycle is a function of a large number of variables, e.g. ratios of several tyre parameters, engine and front and rear wheel inertias, and a number of geometric parameters of which steering head inclination angle is an important one. The sensitivity of this measure to a large number of variables, which vary significantly between motorcycles and depend on the mass of the rider, may account for the lack of success of this variable as a measure of handling quality.

2.4.4 Effect of Rider Control on the Characteristic Modes

The influence of the rider, both as a passive and active element, cannot be ignored. Weir (1972) analysed the rider/cycle combination as an interacting unit, a 'closed-loop' system. Thus emphasis was placed on active rider control, and performance of the combination was explored rather than considering the motorcycle dynamics alone.

Weir's first task was to model the rider's control processes. He investigated single loop systems to determine which feedback cues and control means are most compatible in producing a good control system. The following feedbacks were analyzed: heading angle and rate, roll angle, steer angle, and lateral position, velocity and acceleration.

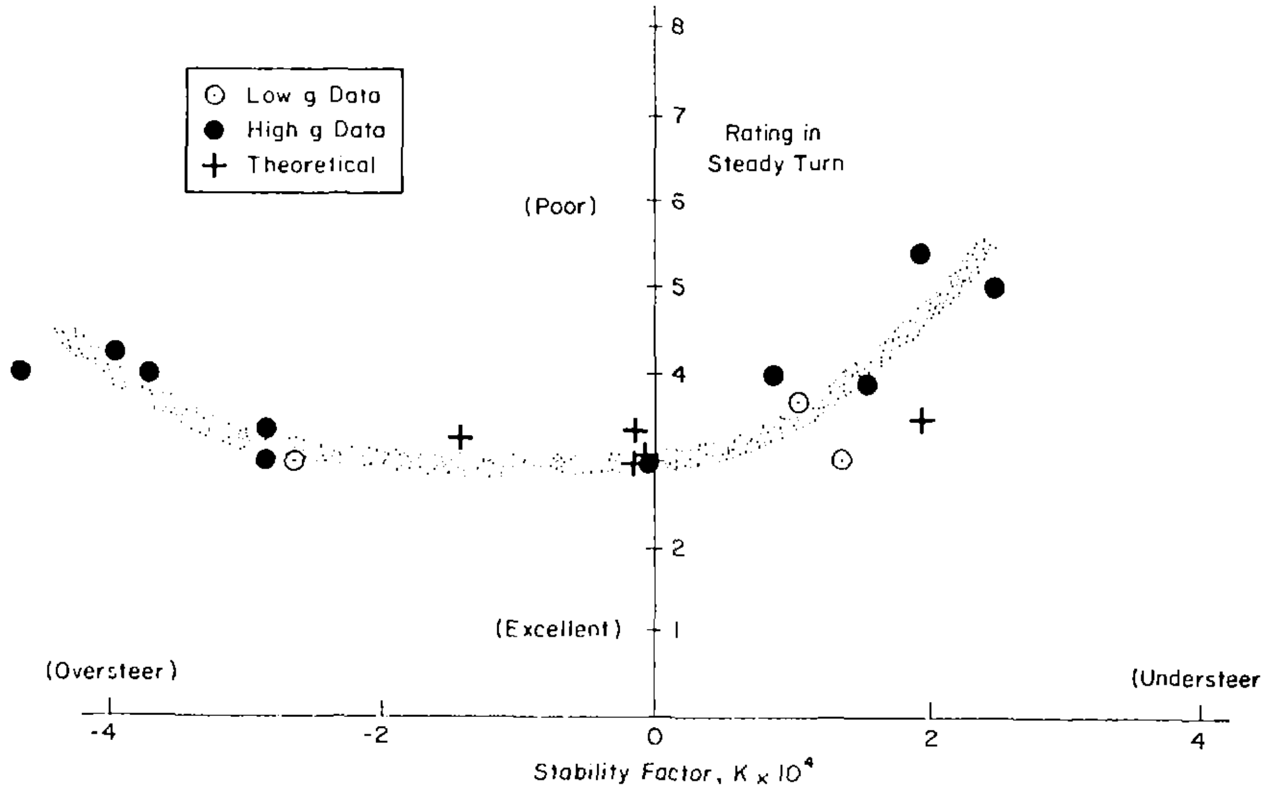

Figure 2.8 Effect of stability factor on rider rating (Weir et al., 1978).

The comparisons which were made were based on control system performance criteria and are not discussed here.

Weir concluded that from the control means of steer angle, steer torque and lean of the rider's upper torso relative to the motorcycle (rider lean), only steer torque and rider lean lead to simple, good rider/cycle control systems. It was found that steer torque response to roll angle error is a very good system with rapid response occurring in a well damped manner. Other good feedbacks were heading rate to rider lean, and roll angle to rider lean. For the example motorcycle studied, rider lean control was considered less effective than steer torque control because of the relatively large rider lean angles required to achieve satisfactory control.

Based on these single loop systems, Weir proposed the multiple-loop rider/cycle structure shown in Figure 2.9. In this model steer torque is used in the inner loop to null roll errors, while (independent) compensatory control of heading angle and lateral position is exercised by means of rider lean. The rider/cycle system was therefore represented as primarily consisting of three loops, an inner, fast, roll stabilization loop and two, slower, outer path following loops. A similar system structure has been used by other researchers (Watanabe and Yoshida, 1973; Roland, 1973).

Weir's analysis showed how the modes of the closed-loop rider/cycle system differ from the open-loop ones because of the rider's control activity. The capsize mode, when it is unstable, may be stabilized by the presence of rider control. Usually, the high frequency weave and wobble modes are largely unaffected by control activity. However, if these modes are lightly damped then the weave mode can be influenced, and sometimes roll stabilization and path following control can (unintentionally) cause instability. If changes in cycle configuration reduce the weave mode frequency, such that it falls within the rider's control frequency range (about 1.5 Hz), then it can become important. The wobble mode frequency is well beyond the rider capability to effect control. However, as mentioned earlier, its oscillatory characteristics can be influenced by the way the rider grips the handlebar.

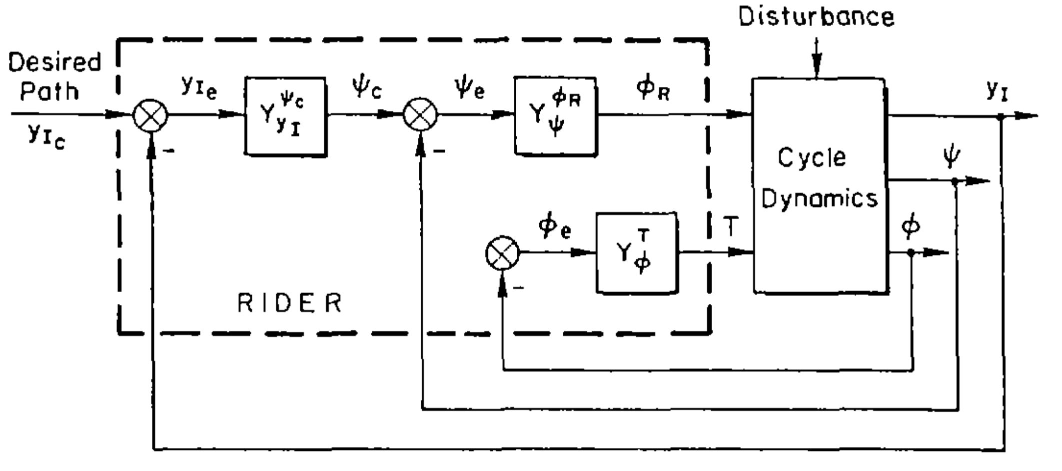

Figure 2.9 Weir's multiple-loop rider/cycle system (Weir, 1972).

2.4.5 Summary and Conclusions

The following conclusions can be drawn from the literature examined pertaining to the dynamics of the motorcycle:

(i) The motorcycle possesses three characteristic modes of motion which are: the capsize mode, which is characterized by aperiodic roll motions; the weave mode, which involves coupled steering, yawing and rolling; and the wobble mode, an oscillatory motion of the front fork about its axis of rotation.

(ii) Continuous rider control activity is required to stabilize the capsize mode roll when this mode is open-loop unstable.

(iii) The weave mode can be influenced by rider control activity.

(iv) Use of steer torque and rider lean as control means appear to be the most effective way to exercise control over the motorcycle. Rider lean can be less effective than steer torque because of the relatively large lean angles which can be required.

(v) Acceleration improves the stability of the capsize mode while deceleration makes it worse.

(vi) Coupling can occur between the in-plane bounce and pitch modes and lateral motion weave mode to produce a lightly damped 'weave' oscillation which, under some operating conditions, may become unstable.

(vii) Under steady turn conditions many motorcycles possess a characteristic 'inversion speed' below which the capsize mode is stable and a steer torque 'out of the turn' is required. Above this speed the capsize mode is unstable and the steer torque direction is reversed.

(viii) The 'stability factor', which is used as a measure of the handling quality of two-track vehicles, has not been shown to provide a useful measure of the handling quality of a motorcycle.

CHAPTER 3

HANDLING CHARACTERISTICS OF THE MOTORCYCLE USED IN THE EXPERIMENTS

3.1 INTRODUCTION

Since this research is concerned with establishing characteristic patterns of rider/cycle behaviour associated with level of skill, it is desirable to have some knowledge of the handling, or control response properties, of the motorcycle used. This is important for the following reasons:

- Knowledge of the handling properties will aid in interpretation of the experimental data and comparison with the results of other (possibly future) studies.

- It is of interest to know the extent to which the motorcycle characteristics are uniform over the range of test speeds used. Uniformity would minimize the importance of variations in test speed.

- It is useful to know of any dynamic characteristics, such as low frequency, lightly damped vibration modes, which may impose an extra workload on the rider.

Tests were conducted aimed at quantifying some of the response properties of the motorcycle - a Honda CB400T. The motorcycle's steady state control gains, and its impulse response properties for different operating conditions were measured. The data acquisition system and transducers used on the motorcycle are described in Appendix A.

3.2 TEST SITE, MOTORCYCLE AND EXPERIENCED RIDER

The Australian Army's Trials and Proving Wing at Monegeetta in Victoria provided the necessary areas to carry out the steady state turn test and impulse response test. A bitumen-surfaced area provided a large enough area for some of the steady-state turn tests. The higher speed, large radius turns were conducted on a curved section of track at the end of the braking straight. The impulse response tests were conducted on the braking straight.

Prior to each day of testing, tyre pressures were checked to ensure they were set at the manufacturer's recommended inflation pressure. The tyres on the motorcycle had covered some 1700 kilometres of relatively hard work (primarily acceleration and braking on straight and curved tracks with very little sustained straight line cruising) and were considered to be well run-in.

The rider used for both tests was of medium build, weighed 68 kg and had 15 years of riding experience, 3 years of which was Enduro competition and 1 year Motor Cross competition.

3.3 STEADY STATE TURN TESTS

These tests were used to measure the steady state control gains, or sensitivities, of the motorcycle. These control properties of the motorcycle relate a control input (e.g. steer torque) to the resultant motion of the motorcycle after any transients have effectively decayed. Control gains are important to the handling quality of an automobile. Their importance to motorcycle handling is still a matter for investigation (Rice et al., 1976; Weir et al., 1978; Watanabe and Segel, 1980).

3.3.1 Test Procedure

The steady state turn tests were limited to examining the cycle's response to steer torque control. The effect of rider lean on the steady state response, although of interest, could not be explored due to time limitations.

During the tests no form of rider lean restraining device was used. It was felt that such a device would make the task at hand more difficult for the rider. Weir et al. (1978) found that, for the skilled rider used during their tests, rider lean was minimal. The test rider used during these experiments was asked to try to maintain his upper torso in the plane of symmetry of the motorcycle. In addition, the variables rider lean and upper torso twist were recorded, which allowed subsequent checking of the magnitude of lean inputs and the extent to which rider twisting influenced the output of the rider lean transducer. The influence of rider lean on the measured variables is discussed in Section 3.3.3.

The test procedure required that a circular path, delineated by white chalk, be followed as closely as possible by the test rider at various constant speeds. Path radius was varied such that, for a given speed, a range of lateral accelerations was achieved. By testing at various speeds, data were obtained for both the linear and non-linear operating regimes of the motorcycle. Table 3.1 details the range of steady state turn test conditions covered.

Although most runs were conducted by following the path in a clockwise sense, nine runs were performed travelling in an anticlockwise sense. This provided a check on the symmetry of the motorcycle and test rider's riding position.

TABLE 3.1

STEADY STATE TURN RADII (m)

Speed (km/h)	Radius (m)			
	Very low*	Low	Mid	High
10	10	-	-	-
20	30	10	7	-
30	50	20	15	12
40	90	40	30	20
50	120	60	40	30
60	-	80	60	50
70	-	110	80	60
80	-	-	110	80

* This refers to the lateral acceleration in g's as follows:

0 to 0.15g	Very low
0.15+ to 0.35g	Low
0.35+ to 0.49g	Mid
0.5g and greater	High

3.3.2 Control and Response Variables

Results from a typical run conducted at a test speed (V) of approximately 30 km/h, for a turn radius (ρ) of 20 m, and travelling in a clockwise sense (to the right), are shown in Figures 3.1(a) - 3.1(h). Probably the best indicator of when steady state turn (S.S.T.) conditions were achieved is the roll rate trace, Figure 3.1(c). The roll rate should be approximately zero for steady state conditions. In Figure 3.1(c) this occurs for the time period beyond 4.0 seconds. Small deviations from zero are caused by the rider regulating his control input to follow the prescribed path.

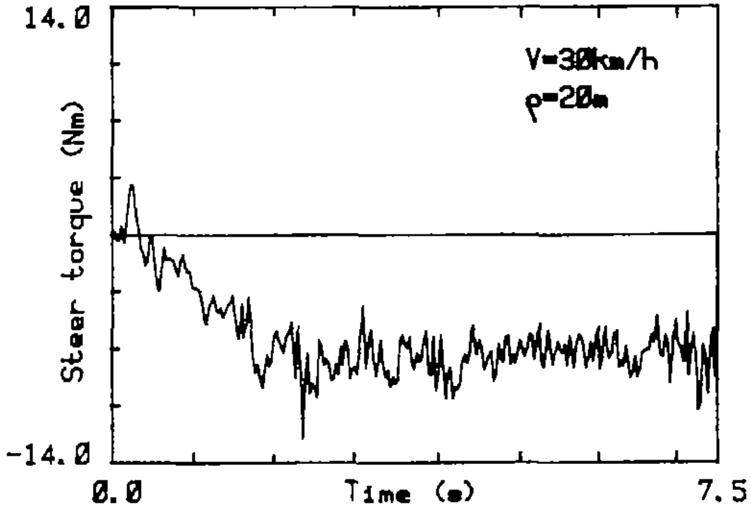

Figure 3.1 (a) Steer torque for typical steady state turn run.

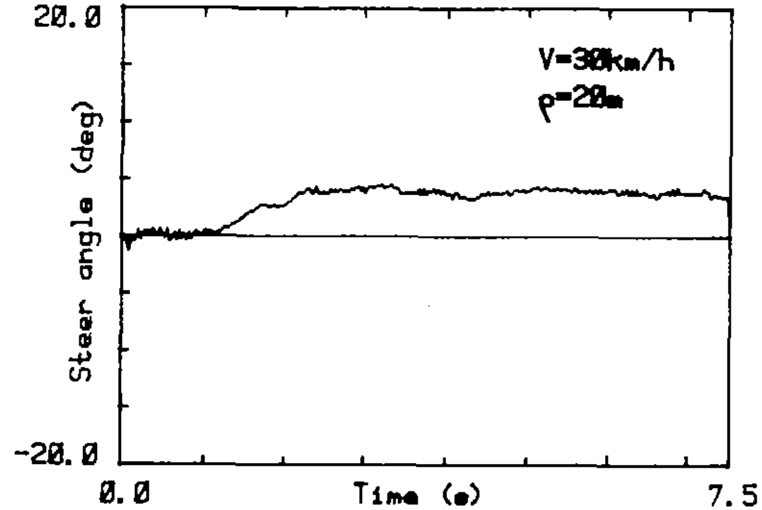

Figure 3.1 (b) Steer angle for typical run.

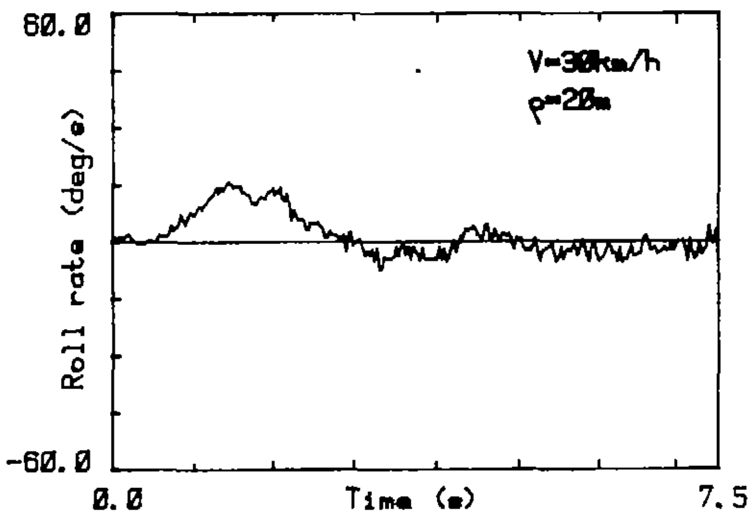

Figure 3.1 (c) Roll rate for typical run.

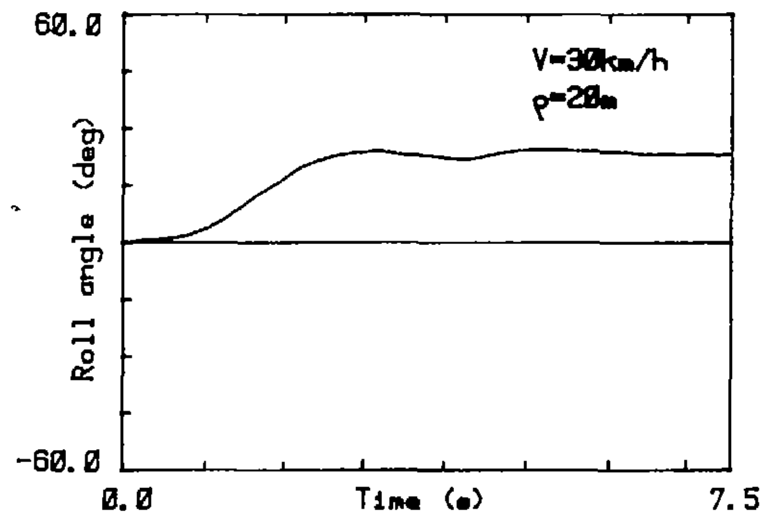

Figure 3.1 (d) Roll angle for typical run.

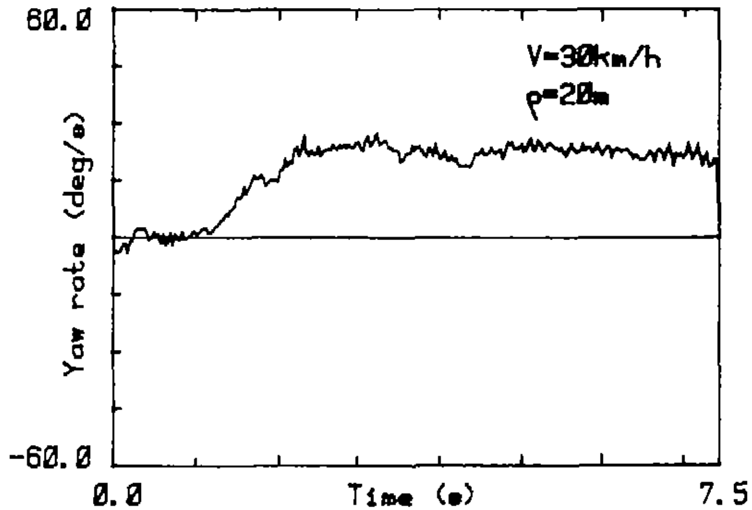

Figure 3.1 (e) Yaw rate for typical run.

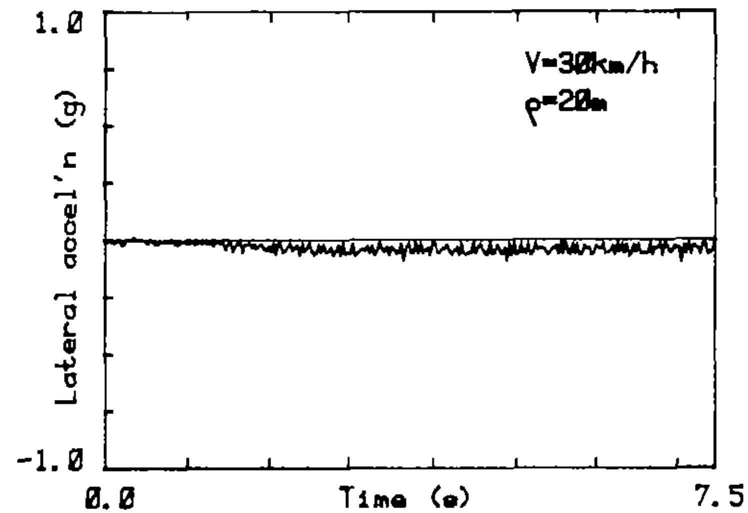

Figure 3.1 (f) Lateral acceleration for typical run.

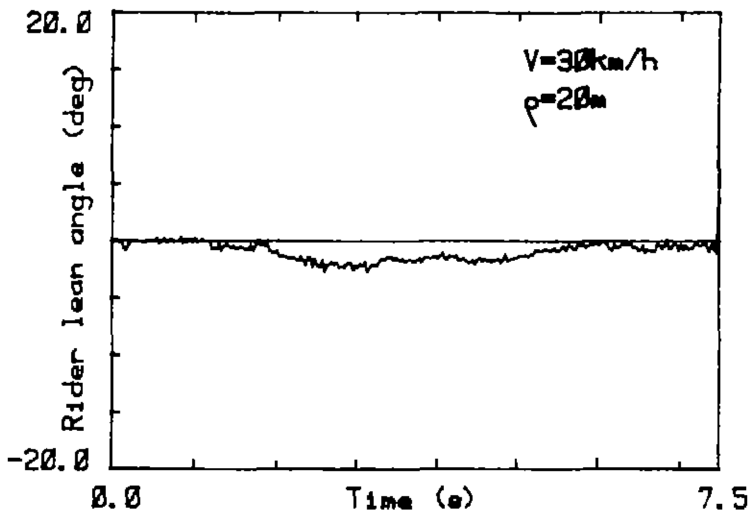

Figure 3.1 (g) Uncorrected rider lean for typical run.

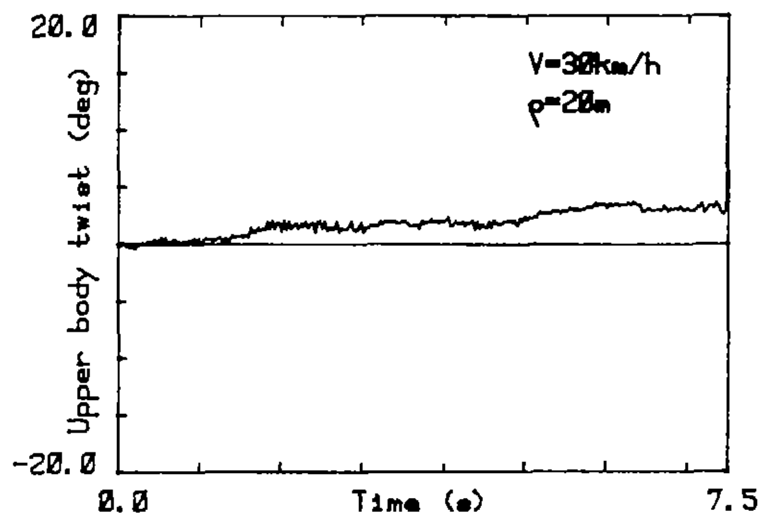

Figure 3.1 (h) Upper body twist for typical run.

The traces show some general features of this motorcycle and rider, at this speed, which are worth examining. The sense of transducer outputs is such that positive directions are defined as forward, to the right and downward. Positive angular displacements involve clockwise rotations about axes pointed in these directions.

The steer angle trace shows that in order to maintain a steady turn to the right the steering assembly must be displaced to the right. Steering torque on the other hand must be applied in a negative direction, opposite that of steer angle, to maintain the required positive steering displacement. The rider is therefore pushing the steering assembly out of the turn. Roll angle (obtained by integrating the roll rate trace) and yaw rate show the cycle to be rolled and yawing to the right (a necessary condition for all motorcycles). Note that the yaw rate shown is a body-fixed component, as measured directly by the yaw gyro. Lateral acceleration is seen to be approximately zero, as expected, since the accelerometer is also body-fixed and the turn is co-ordinated. The residual negative acceleration indicated by the accelerometer is due to the fact that the steady roll angle of the motorcycle is required to be slightly greater than the inclination of the resultant 'body force' on the accelerometer (see later). The upper-body twist trace indicates an angular displacement proportional to the steer displacement and equal in sign. Uncorrected lean angle is slightly (2.0 deg maximum) to the left relative to the plane of symmetry of the motorcycle. Interpretation of the upper-body motion transducer outputs is discussed in detail in Appendix J. Speed (not shown) was maintained at a constant value of about 30 km/h.

To obtain steady state values for each variable, mean values for transducer outputs were estimated by positioning a line through the portion of data believed to be steady state. Estimates for the various transducer outputs are shown in subsequent figures as a function of speed and the lateral acceleration in a horizontal plane. Lateral acceleration as measured on the motorcycle is not shown because values were not significantly different from zero. Any subsequent references to lateral acceleration refer to the lateral acceleration in the horizontal plane, $V^2/\rho g$.

(a) Steer torque

Linear analysis of motorcycle dynamics predict that, if curves of successively decreasing radius are driven at the same speed, the steer torque required to maintain a steady turn will increase in proportion to the lateral acceleration (Watanabe and Segel, 1980). The constant of proportionality is expected to be a function of the forward speed; indeed for many motorcycles the constant changes sign at a 'transition speed' (Section 2.4.3).

Figure 3.2 shows the variation of mean steer torque with lateral acceleration measured for the test motorcycle at a number of values of forward speed. The relationship is clearly nonlinear, with the steer torque 'saturating' to a fairly constant value for lateral accelerations higher than 0.2g to 0.3g. It is apparent that the relationship varies with forward speed also.

The effect of speed can be seen in Figure 3.3, where torque is plotted against forward speed, various ranges of lateral acceleration being indicated by the different plot symbols. The size of the steer torque required for a given lateral acceleration decreases as the speed increases from 10 to 30 km/h, with little variation at higher speeds. There is no evidence of a transition speed for this motorcycle: the steer torque required for a positive (right-hand) turn is consistently negative, and vice versa.

The steer torque characteristics shown in Figures 3.2 and 3.3 indicate that the test machine does not give particularly useful feedback to the rider, by way of steer torque, about the operating conditions. The general importance of such 'feel' characteristics to handling quality is not known. Watanabe and Segel (1980), however, made the following comment on the basis of their study of steady state characteristics:

> "Although one might conjecture that riders are sensitive to the magnitude and polarity of the torques required to hold a cycle in a steady turn, the test experience obtained in this study suggests that such is not the case."

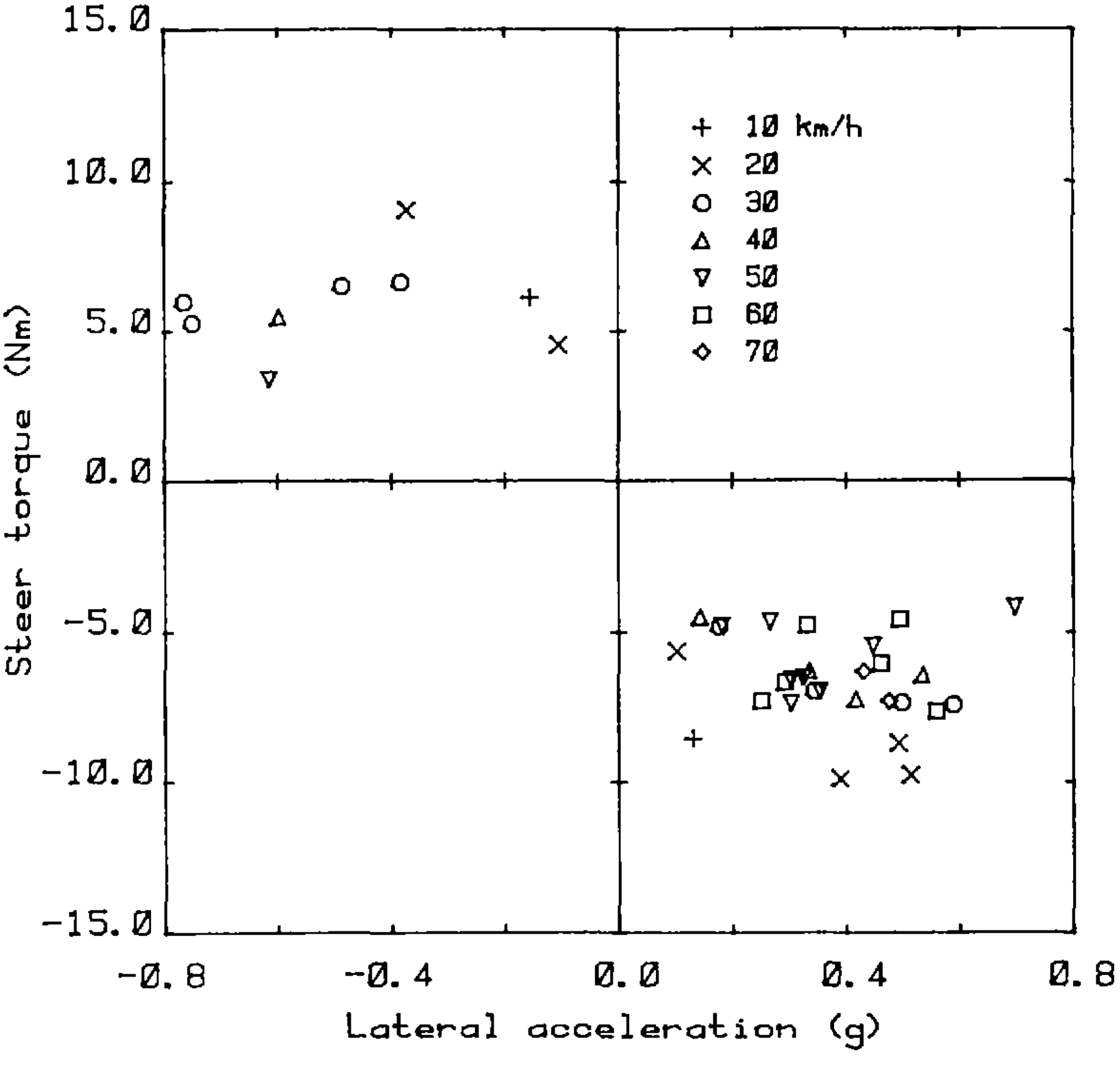

Figure 3.2 Steer torque versus lateral acceleration with speed as a parameter.

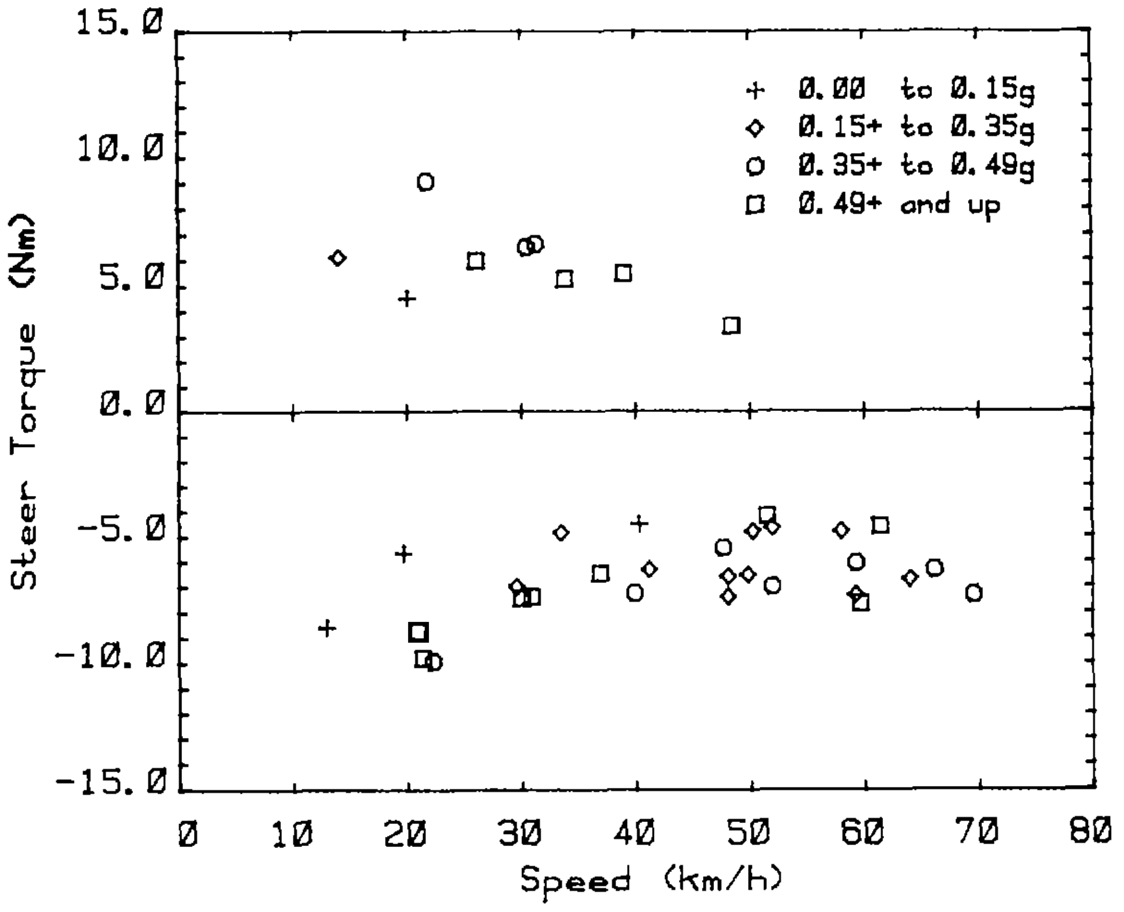

Figure 3.3 Steer torque as a function of speed for different ranges of lateral acceleration.

(b) Steer angle

For a four-wheeled vehicle of wheelbase L, the steer angle δ required to produce a turn of radius ρ at very low speeds is given by the Ackermann angle $\delta = L/\rho$. As the speed is increased, the steer angle required to track the same radius curve will decrease or increase, depending on whether the vehicle understeers or oversteers, respectively. For a motorcycle, the expression for the Ackermann angle is modified as a result of the rake angle of the steer axis λ and the inclination of the front wheel (which may be approximated by the roll angle ϕ), so that

$$\delta \approx \frac{L/\rho}{\cos\lambda \cos\phi} \qquad (3.1)$$

Again, the understeer/oversteer properties of the motorcycle will cause the actual steer angle to deviate from this approximate value in proportion to the lateral acceleration.

In Figure 3.4 the measured steer angles are plotted against curvature of the turn, $1/\rho$, for different ranges of lateral acceleration. Also shown is the relationship predicted by equation (3.1), with the linear approximation $\cos\phi \approx 1$. It can be seen that the measured values deviate from the Ackermann angle by only small amounts, but in a direction indicating that the test motorcycle was oversteering. The oversteer properties are investigated in more detail in Section 3.3.4. Figure 3.4 also demonstrates that very small steer angles are required for curves negotiated at highway speeds ($\rho > 20$ m, say). It is also noteworthy that, within the range of test speeds (10–70 km/h), positive steer angles are always required for a positive (right-hand) turn and vice versa. It is shown in Section 3.3.4 that this oversteering bike has a critical speed of about 87 km/h; above this speed negative steer angles would be required for positive turns. The skill experiments, however, were restricted to speeds less than 40 km/h.

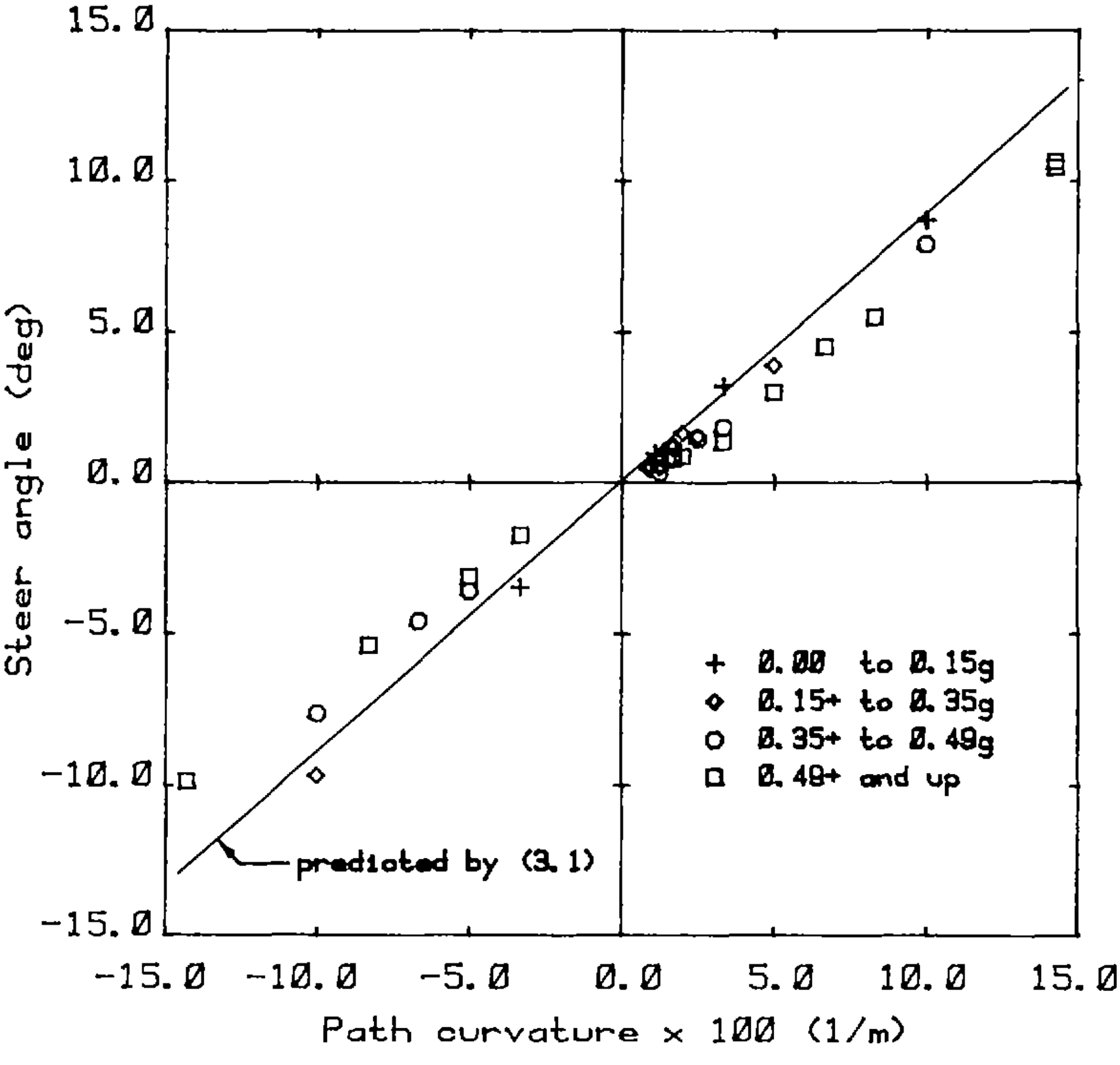

Figure 3.4 Measured steer angle versus curvature of the turn for different ranges of lateral acceleration.

(c) Roll angle

If the rider does not lean his body substantially relative to the motorcycle plane of symmetry (which is the case for the present tests - see Figure 3.1(g)), then a simple analysis indicates that the cycle roll angle ϕ in a steady turn of radius ρ at speed V will be approximated by the inclination of the resultant of the centrifugal and gravitational 'body forces',

$$\phi = \text{artan}(V^2/\rho g), \tag{3.2}$$

where g is the acceleration due to gravity. This relationship is compared with the measured data in Figure 3.5. It is apparent that the motorcycle generally rolled slightly more than the angle given by equation (3.2). This is consistent with the analysis of Fu (1966), Ellis and Hayhoe (1973) and Watanabe and Segel (1980), who show that such an increase in roll angle is required to overcome the gyroscopic effects of the wheels and engine and because of the lateral shift of the resultant tyre forces caused by the finite cross-sectional radius of the tyres.

(d) Yaw rate

Another motorcycle variable measured was the yaw velocity about the body-fixed z axis; i.e. an axis fixed in the rear frame of the bike which is vertical when the plane of symmetry of the bike is vertical. This body-fixed component of the yaw rate, r, is related to the total yaw rate (about a vertical axis), R, by the relation

$$R = r/\cos\phi. \tag{3.3}$$

The total yaw rate for a curve of radius ρ, driven at speed V, is in turn given by

$$R = V/\rho \tag{3.4}$$

A good check on the consistency of the steady-turn data is to compare the total yaw rate derived from these two expressions, as is done in Figure 3.6. The agreement shown there is considered to be very good

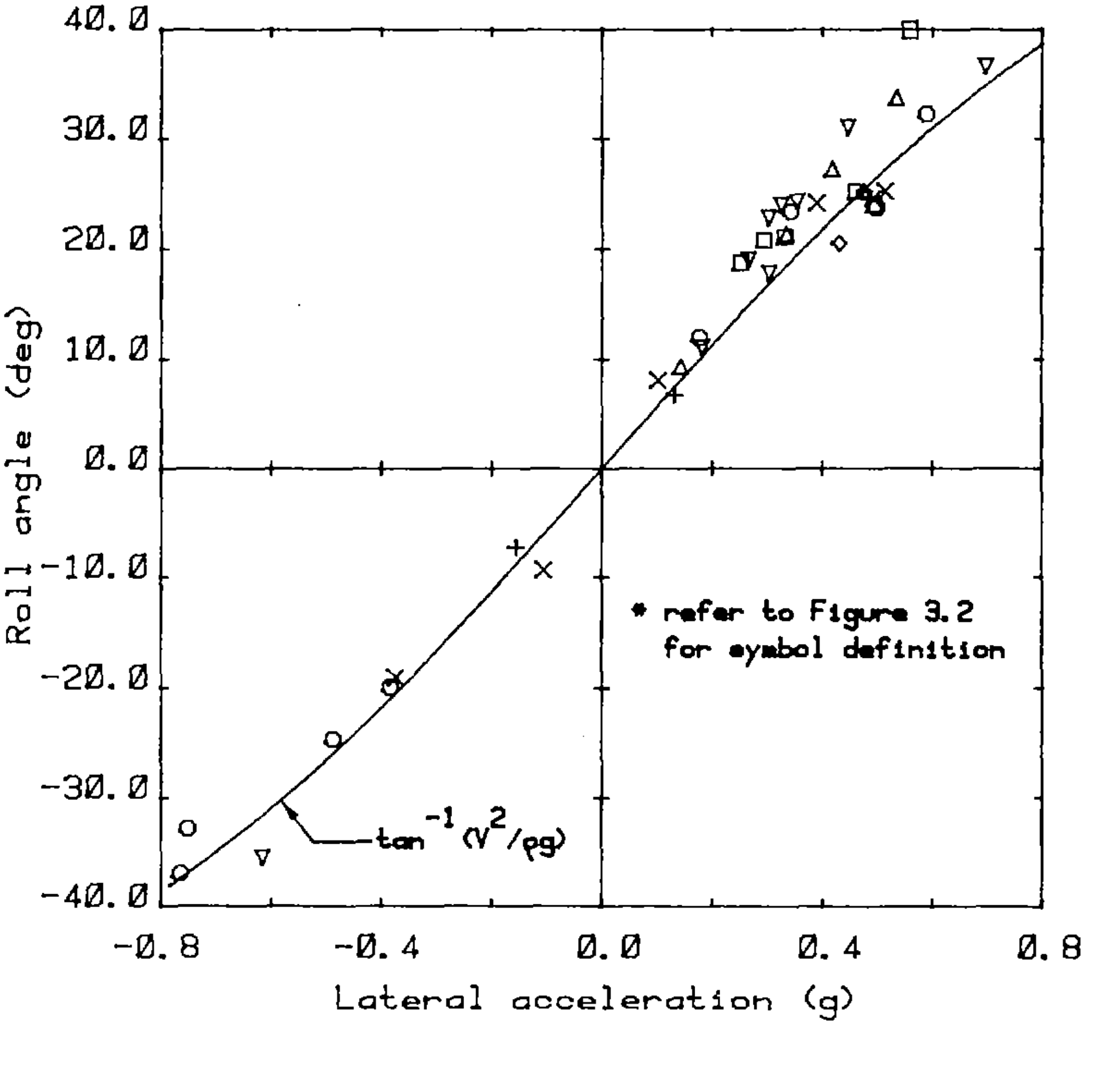

Figure 3.5 Measured and predicted roll angle versus lateral acceleration for various speeds.

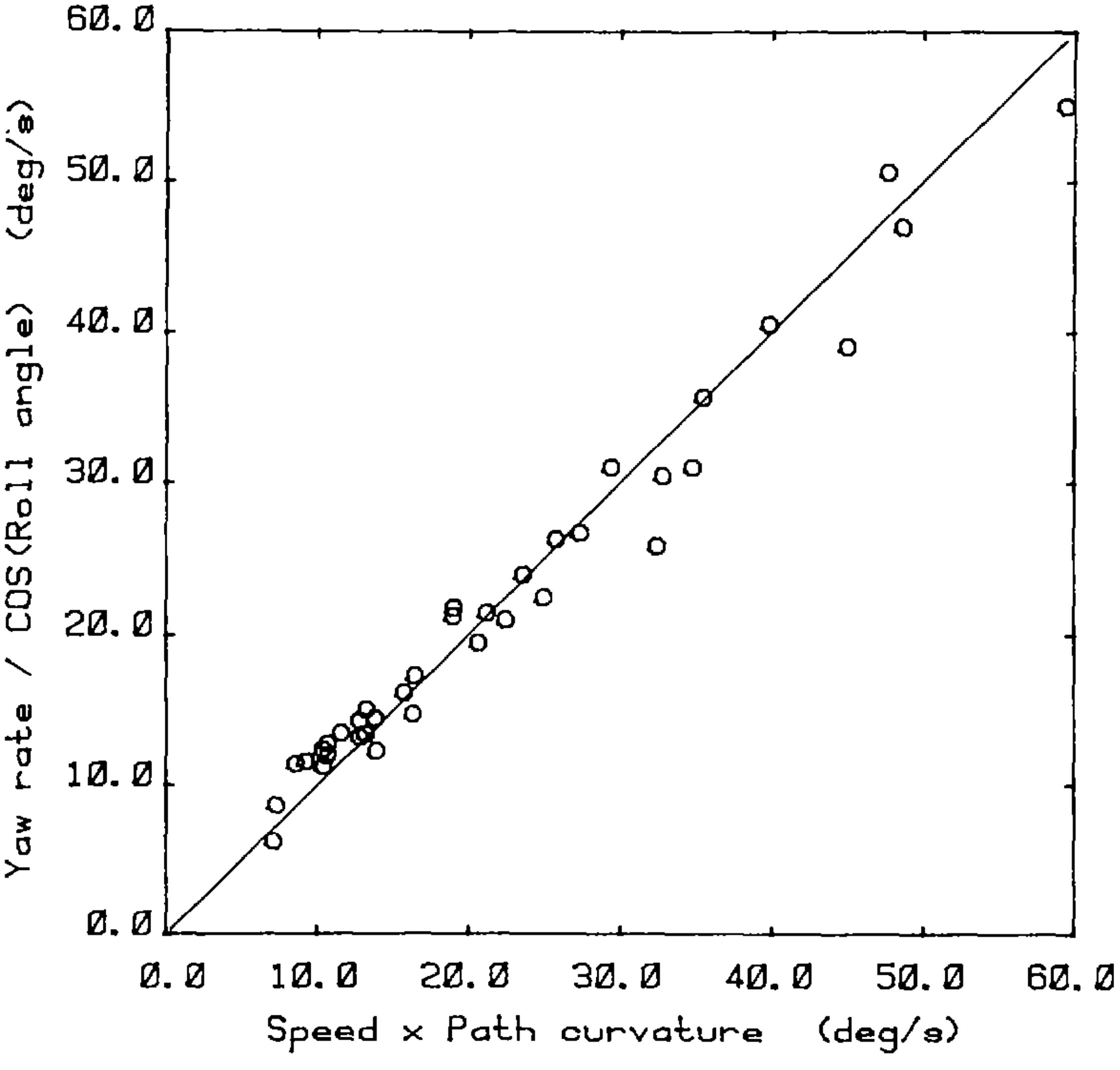

Figure 3.6 Comparison of total yaw rate derived from expressions (3.3) and (3.4) for measured data.

when it is recalled that errors could arise from the following processes:

(i) the body-fixed yaw rate r was measured with a rate gyroscope;

(ii) the roll angle ϕ was obtained by integrating the output of a rate gyroscope;

(iii) the speed V was measured with a speed transducer, the calibration of which depends on the rolling radius of the front tyre (which varies with the roll angle of the bike);

(iv) the radius ρ is the radius of the chalked curve which the rider attempted to track as closely as possible.

3.3.3 Steady State Control Gains

This section examines the steady state control gains, or sensitivities, of the motorcycle, where steer torque is taken to be the control input. The motorcycle responds to rider lean, also. However, despite the lack of any physical restraint, the test rider was able to restrict his lean to a mean value of only 1.3 degrees, with a standard deviation of 2.4 degrees. As the test motorcycle does not possess a 'transition speed' (at which both the lean and torque gains approach very large values), it is fairly insensitive to lean inputs over the entire test speed range. It can be expected therefore that the control gains presented in this section properly represent the test motorcycle's response to steer torque inputs only.

As indictated previously, some steady state control gains are likely to be important indicators of the handling qualities of a motorcycle. However, different machines have been shown to have strikingly different control gain characteristics; the importance of this to differences in handling quality remains an open question. To illustrate some of this variability, and to provide a reference for the present tests on a Honda CB400T, the measured control gains are compared in this section with those predicted and measured for a Honda 360G by Weir et al. (1978). Both motorcycles would be classified as medium-size street machines; general comparison data are given in Table 3.3.

(a) Torque/roll ratio

The torque/roll ratio (the steady-state steer torque input required per unit of roll angle response) is likely to be of some importance to riders, because it appears that roll control and stabilization via steer torque forms a major part of the rider's control activity - see Section 2.4.4

Figure 3.7 shows the torque/roll ratio measured for the test motorcycle as a function of forward speed, for several ranges of lateral acceleration. It should be noted that no distinction is made between the left and right turn runs because there was an indiscernible difference between the data. For comparison, Weir et al's (1978) measurements on a Honda 360G are shown in Figure 3.8, together with the predictions of a linearized model of the vehicle dynamics.

It can be seen that the Honda 360 has a 'transition speed' of about 25 mph (40 km/h) at which the sign of the roll gain changes, and above which the capsize mode is unstable. For the present test motorcycle, however, the sign of the roll sensitivity remains negative over the whole test speed range.

Note that the linearized model (which assumes no variation of tyre characteristics with forward speed) predicts a single roll gain - speed characteristic, independent of lateral acceleration. Some sensitivity to lateral acceleration can be seen in the data for the present motorcycle, however, due to its nonlinear relationship between steer torque and lateral acceleration (Figure 3.2). The effect is to reduce the steer torque requirement at a given speed as the lateral acceleration is increased.

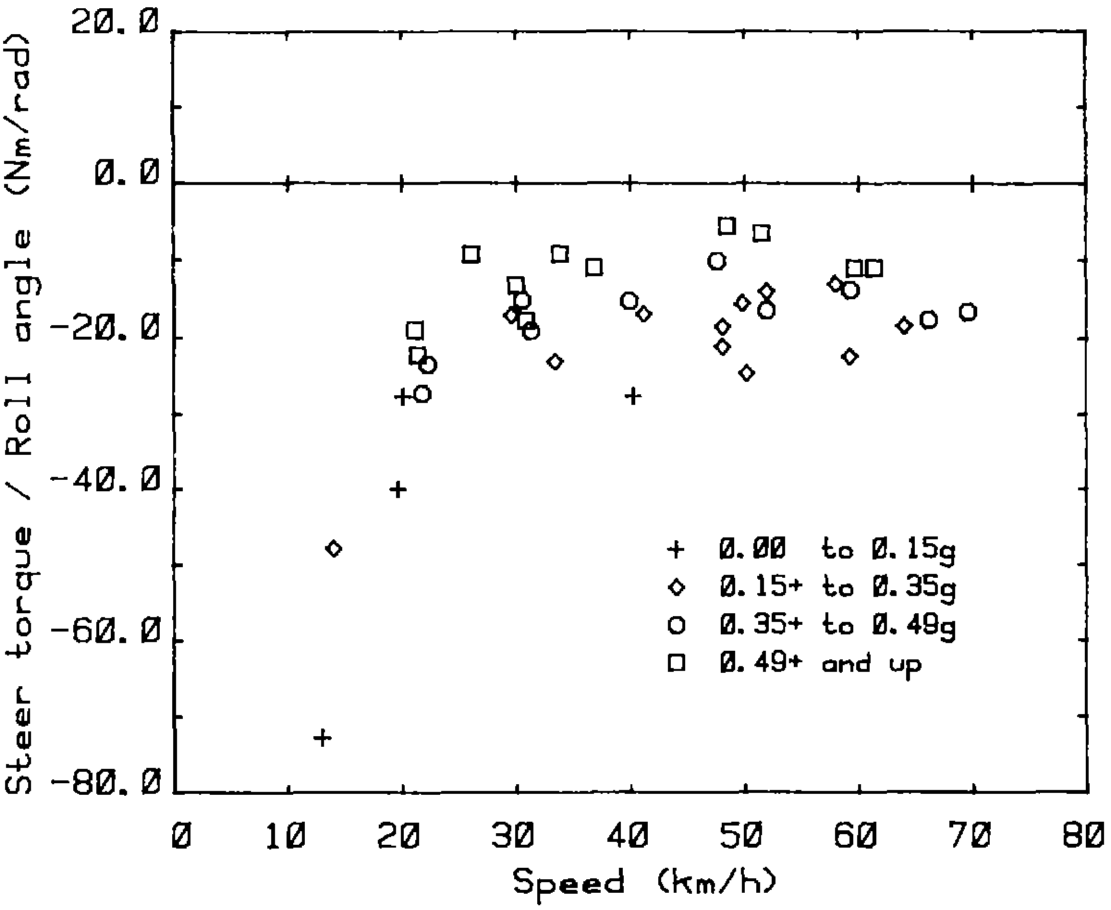

Figure 3.7 Variation of steer-torque/roll-angle gain with forward speed, Honda CB400T.

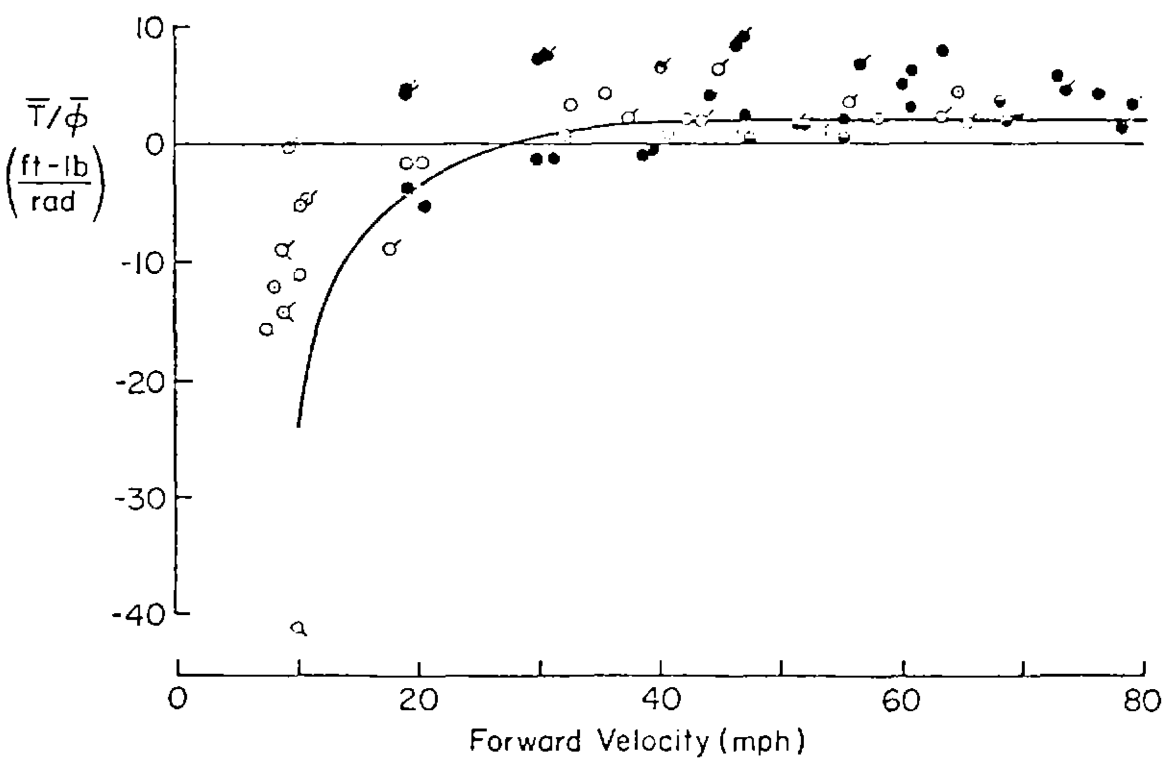

Figure 3.8 Variation of steer-torque/roll-angle gain with forward speed, Honda 360G (Weir et al., 1978).

(b) Steering stiffness

Figures 3.9 and 3.10 show the ratio of steer torque to steer angle, i.e. the 'stiffness' presented to the rider by the steering system, for the Honda 400 and 360 respectively. Whereas the steering stiffness of the test motorcycle becomes increasingly negative as speed increases, the sign change in the torque characteristic of the Honda 360 causes exactly the opposite effect. The nonlinear torque characteristic of the Honda 400 results in a reduction in the magnitude of its steering stiffness with increasing lateral acceleration.

(c) Torque/yaw rate ratio

The inverse gain relating steer torque input per unit yaw rate response is shown in Figures 3.11 and 3.12 for the test and comparison motorcycles, respectively. The comments just made about the steering stiffness plots apply equally here.

3.3.4 Stability Factor

It is generally accepted that the directional control of automobiles is primarily by way of steer angle rather than steer torque. The variation of the yaw-rate/steer-angle gain with speed is thus widely used as an indicator of the understeer/oversteer characteristic of an automobile. For lateral accelerations less than 0.3g the vehicle response is linear and the yaw rate gain is given by (Segel, 1956-57):

$$\frac{r}{\delta} = \frac{V}{L(1 + KV^2)} \qquad (3.5)$$

In this expression L is the vehicle wheelbase. The stability factor, K, is positive, zero or negative according as the vehicle is understeer, neutral steer or oversteer. For an understeer vehicle the yaw rate gain r/δ is reduced to half its low speed value at the 'characteristic speed' $V_{ch} = K^{-1/2}$. For an oversteer vehicle, the

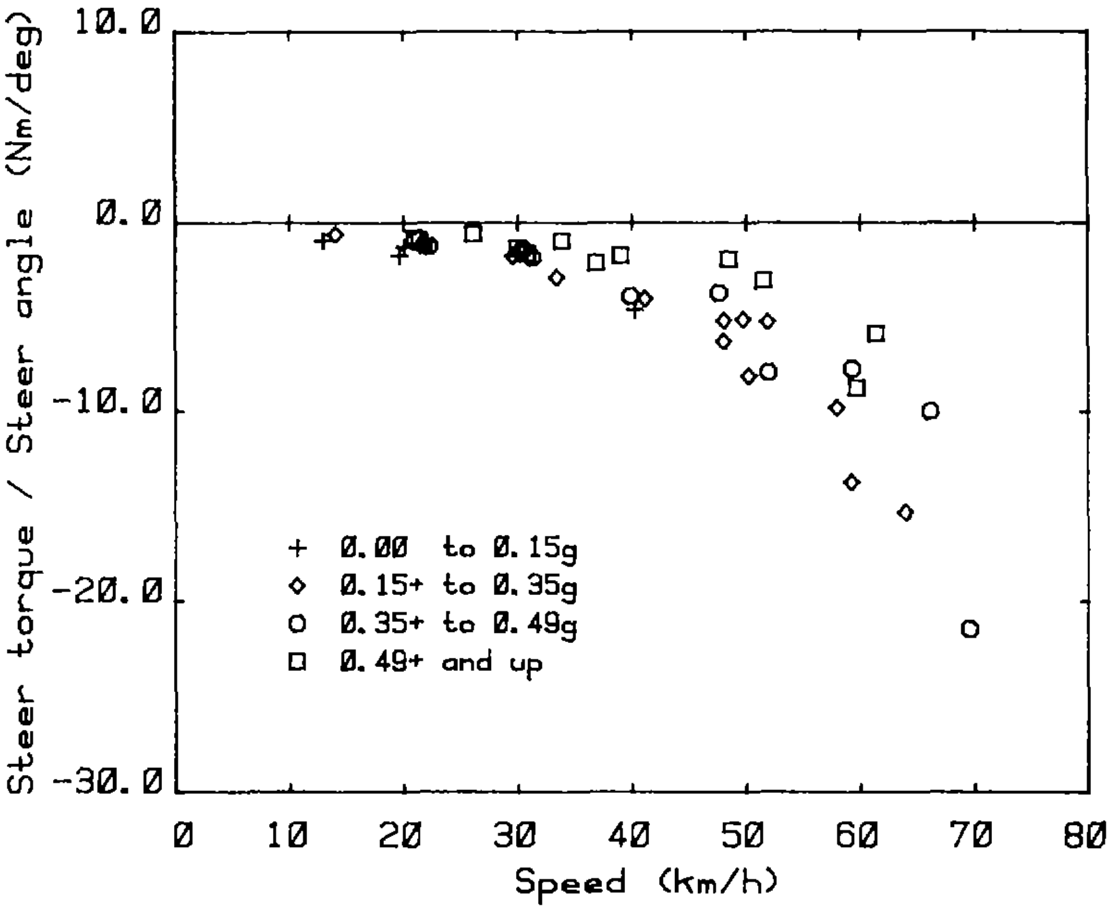

Figure 3.9 Variation of steer-torque/steer-angle gain with forward speed, Honda CB400T.

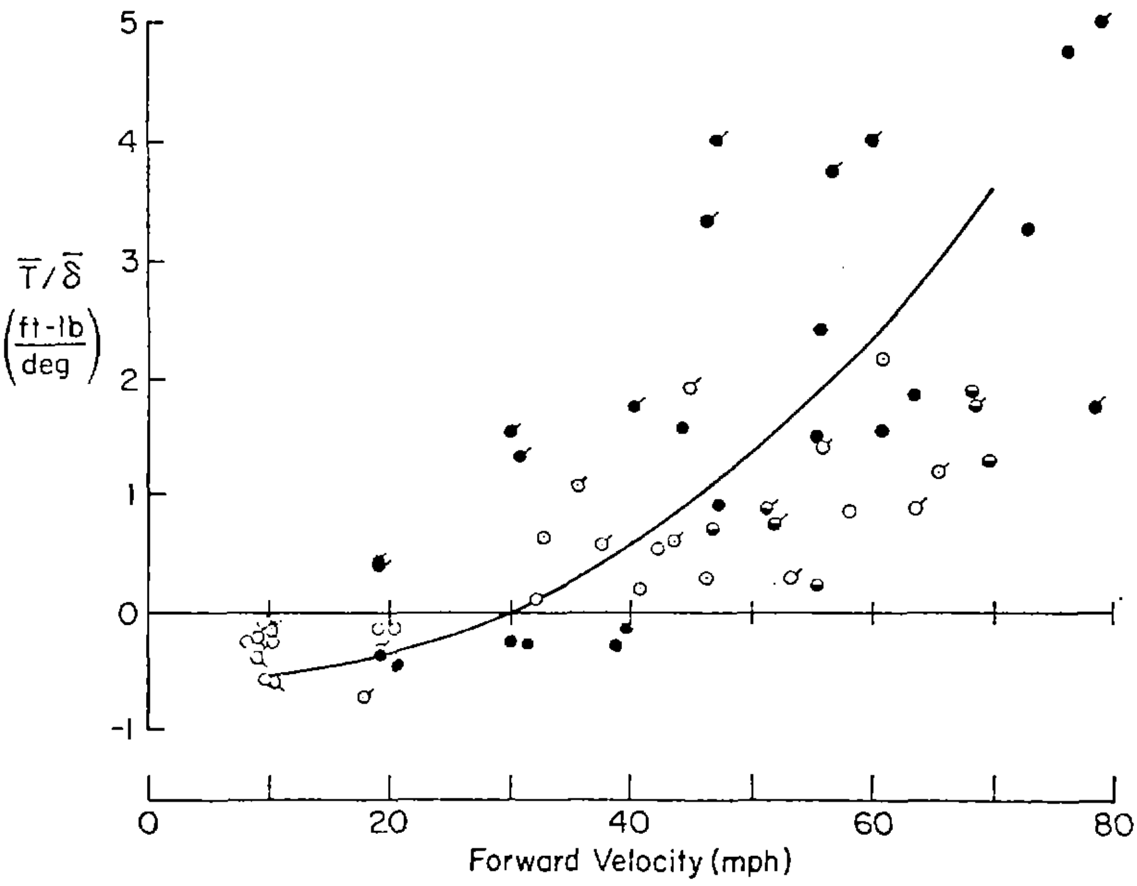

Figure 3.10 Variation of steer-torque/steer-angle gain with forward speed, Honda 360G (Weir et al., 1978).

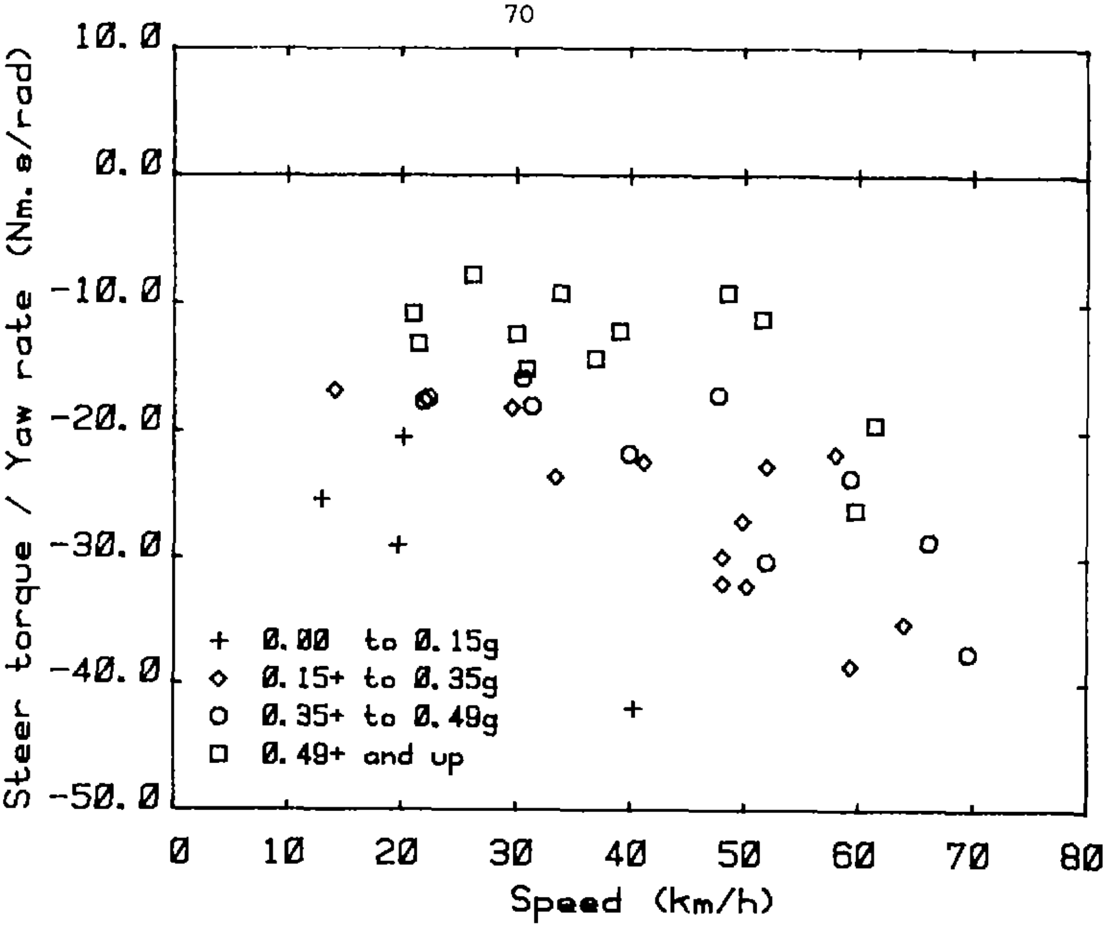

Figure 3.11 Variation of steer-torque/yaw-rate gain with forward speed, Honda CB400T.

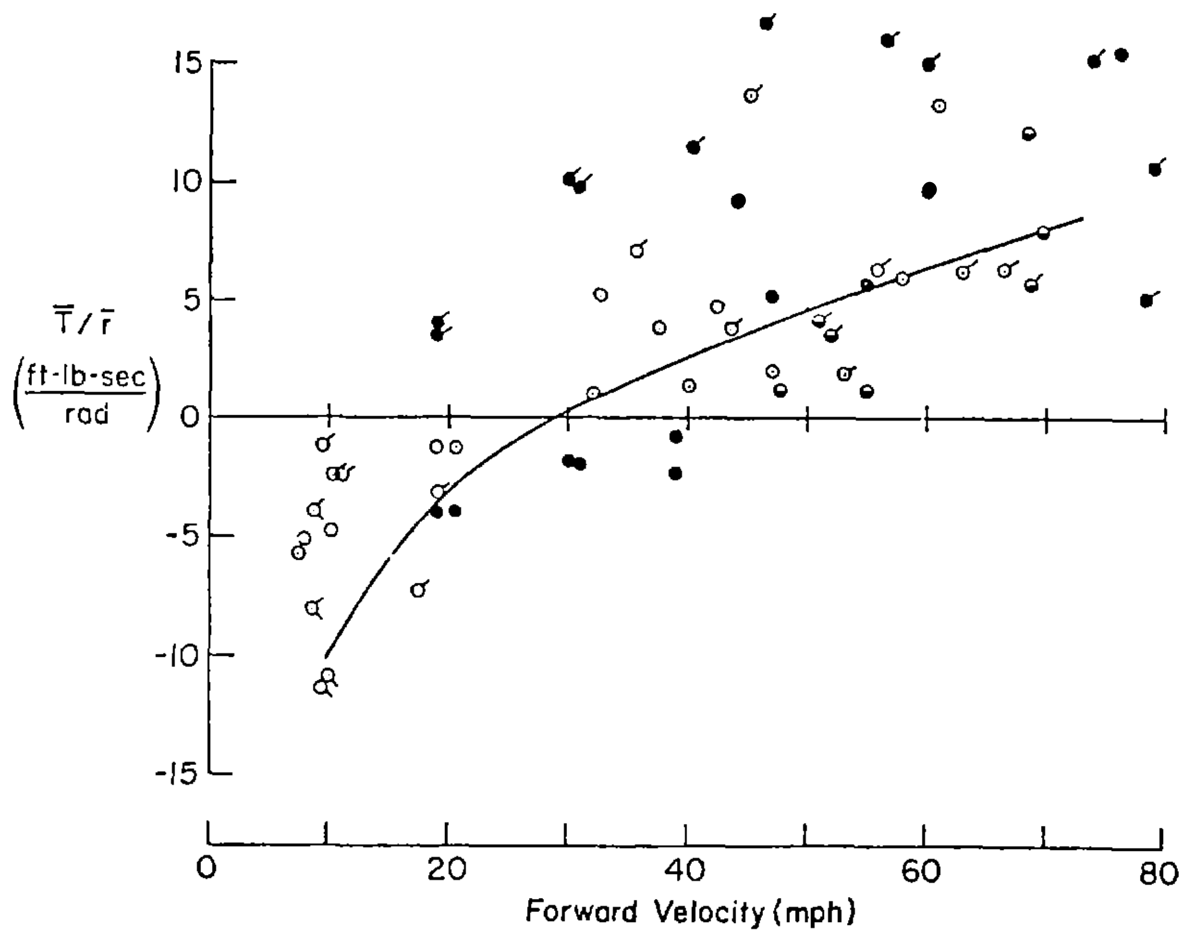

Figure 3.12 Variation of steer-torque/steer-angle gain with forward speed, Honda 360G (Weir et al., 1978).

steady-state gain approaches infinity at the 'critical speed' $V_{cr} = (-K)^{-1/2}$; the response to steer angle inputs is unstable for higher vehicle speeds. The stability factor thus plays a decisive role in determining the nature of both the steady state and transient response behaviour of four-wheeled vehicles.

Motorcycles, on the other hand, are thought to be controlled by steer torque rather than steer angle. According to Watanabe and Segel (1980), the stability factor is not a significant measure of the directional control quality of the motorcycle. Nevertheless, the yaw rate gain of a motorcycle can be determined from the same expression, equation (3.5), provided L is interpreted as an 'effective wheelbase'.

Preliminary investigations by Weir et al. (1978) indicated that their skilled test rider preferred motorcycles with neutral to modest oversteer properties when performing a lane change manoeuvre. This is in contrast to the automobile situation, where a degree of understeer is generally required.

Figure 3.13 shows that the yaw-rate/steer-angle gain for the present motorcycle increases strongly with speed, an oversteer characteristic, and is quite insensitive to lateral acceleration. By contrast, Weir et al.'s Honda 360 was predicted to be neutral steering, while experimentally it proved to be understeering (Figure 3.14).

The stability factor K and the effective wheelbase L can best be obtained by rearranging equation (3.5) to

$$\frac{\delta V}{r} = L(1 + KV^2), \tag{3.6}$$

and plotting the experimental data in the same format, as in Figure 3.15. The stability factor is obtained as the slope of the resulting straight line; the effective wheelbase may then be computed from the zero-speed intercept.

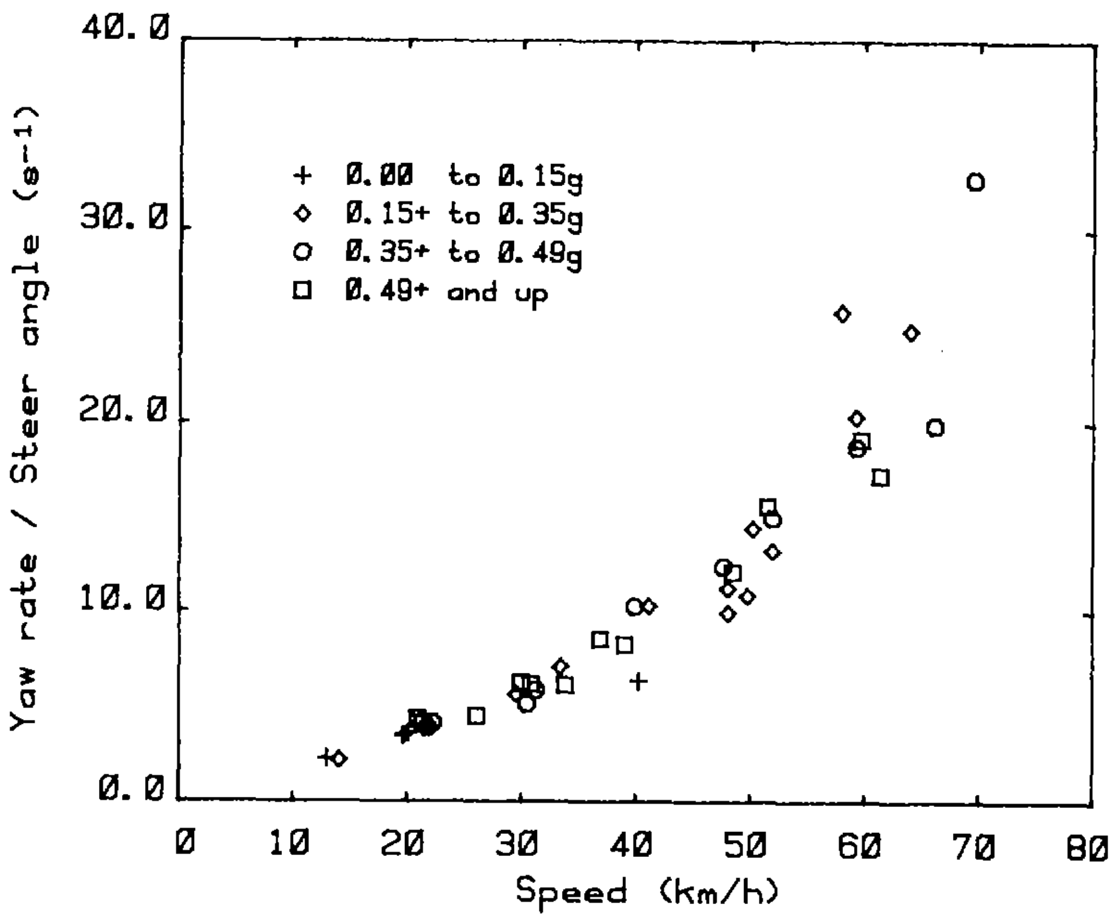

Figure 3.13 Variation of yaw-rate/steer-angle gain with forward speed, Honda CB400T.

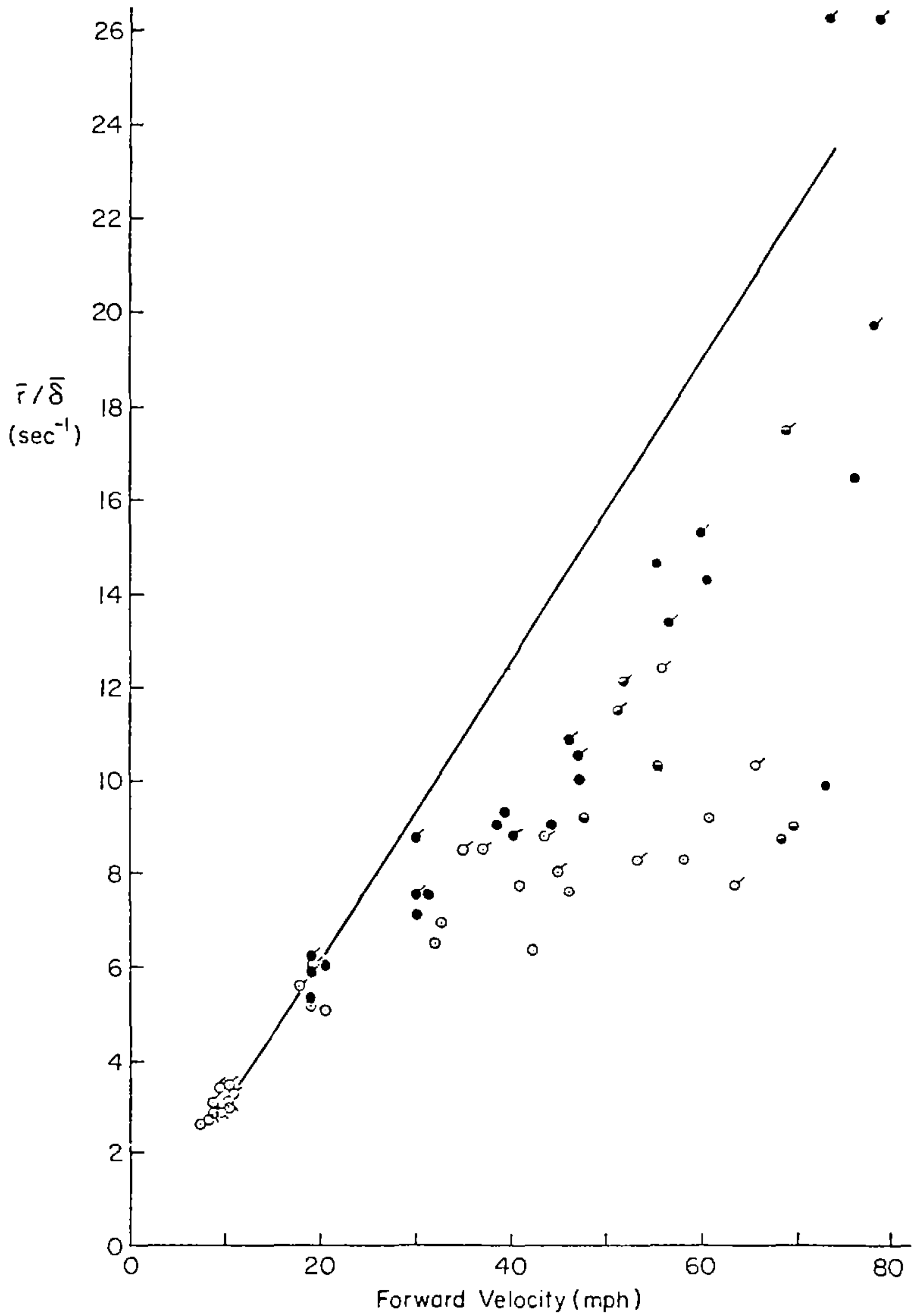

Figure 3.14 Variation of yaw-rate/steer-angle gain with forward speed, Honda 360G (Weir et al., 1978).

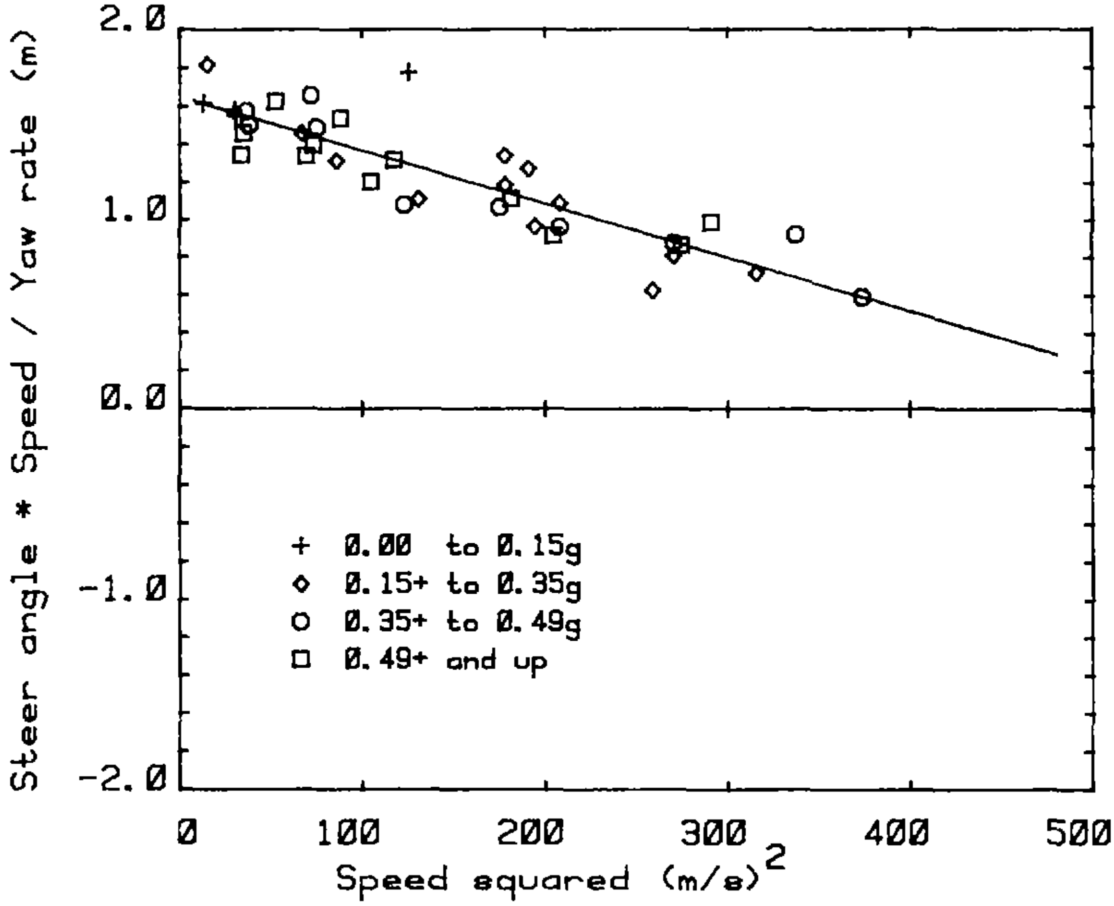

Figure 3.15 Determination of stability factor for the Honda CB400T.

Performing linear regressions on the data shown in Figure 3.15, firstly for lateral accelerations less than 0.35g and secondly for all the data, yielded values which were not significantly different, confirming the lack of sensitivity to lateral acceleration. Using all the data results in an effective wheelbase of L = 1.65 m and a stability factor $K = -17.2 \times 10^{-4}\ s^2/m^2$, corresponding to a critical speed of $V_{cr} = 87$ km/h.

These values are compared in Table 3.2 with those measured by Weir et al. (1978) for three other motorcycles at low lateral acceleration levels. Table 3.3 gives general data for these motorcycles to give an idea of relative sizes. The stability factor comparison shows a wide variation between vehicles, all of which presumably have 'reasonable' handling characteristics.

TABLE 3.2

COMPARISON OF STEERING CHARACTERISTICS OF DIFFERENT MOTORCYCLES

Motorcycle	Stability Factor $Kx10^4\ (m/s)^{-2}$	Effective Wheelbase (m)
Honda CB-125	-28.42	1.37
Honda CB-360G	14.53	1.53
Honda CB-400T*	-17.22	1.65
Harley Davidson FLH-1200	10.98	1.77

* Used in present study

TABLE 3.3

GENERAL DATA FOR COMPARISON MOTORCYCLES

Manufacturer and model	Purpose	Displacement (cc)	Mass (kg)	Wheelbase (m)	Rake angle (deg)
Honda CB-125	Street	125	182*	1.22	27
Honda CB-360G	Street	360	258*	1.35	28
Honda CB-400T	Street	395	258+	1.39	27
Harley Davidson FLH-1200	Touring	1200	448*	1.44	28

* this mass includes a 73 kg rider and 17 kg of instrumentation.

+ this is for the fully instrumented present study test motorcycle with 73 kg rider.

3.4 IMPULSE RESPONSE TESTS

3.4.1 Introduction

As discussed in Section 2.4 the response of a (linear) motorcycle to steer torque and rider lean control is dominated by three natural modes, termed the capsize, weave and wobble modes. The response of the machine results from the linear superposition of the responses to the control inputs of each of the natural modes. The time constants or natural frequencies of the modes determine whether these responses are amenable to rider control; their damping ratios influence the speed and stability of the responses.

Many motorcycles have a transition speed, above which the aperiodic capsize mode is unstable, and some attention is required from the rider to stabilize the roll behaviour of his machine. It was seen in Section 3.3 that the present motorcycle does not have a transition speed (at least, not below 80 km/h) and so its capsize mode can be expected to be stable. The natural frequencies of the weave and wobble modes are generally too high for the rider to be able to exercise effective control over their responses.

The natural modes of the closed-loop rider/cycle system differ from the cycle-alone modes because of the rider's intervention. The major changes occur to the low-frequency modes; rider control and the inertia of the rider's arms may also influence the higher frequency wobble mode.

The objective of the impulse tests described in this section was to determine the natural frequencies and damping ratios of the cycle-alone weave and wobble modes. (By 'cycle-alone' is meant cycle plus a passive rider exerting no control.) Because the capsize mode time constant is so large (typical values are of the order of 5 to 10 s) it is very difficult to identify from experimental data. In any case, for the test motorcycle the capsize mode was stable; the value of its time constant is correspondingly less interesting.

Two previous experimental studies of the uncontrolled motorcycle over a wide range of speeds have been conducted by Eaton (1973) and Verma (1978). The study by Eaton was concerned primarily with establishing the nature of the rider describing function for roll control of the motorcycle. Only a small part of his experiment was concerned with establishing the behaviour of the natural modes. His results were generally qualitative and relate only to the wobble mode as he was unable to excite a measurable weave oscillation, except when this mode was unstable (at quite low speeds). In relation to the wobble mode of his test machine (a Honda CL175), Eaton observed that "the wobble mode was observed experimentally to have nearly constant damping and frequency throughout the speed range, even at zero speed".

Verma's experiments were more extensive and detailed information related to natural frequencies, damping ratios and mode shapes (the relative displacement configuration of the motorcycle associated with each natural frequency) is presented in his report. Results from the present experiments are compared with Verma's in the following sections.

3.4.2 Procedure

To excite one natural mode only, to the exclusion of the others, is an impractical proposition for a motorcycle. An alternative procedure is to provide the motorcycle with a disturbance which covers a broad range of frequencies, thereby exciting each mode of interest simultaneously. By assuming the response of the motorcycle to be linear, and realizing that the response of a linear system to any disturbance may be studied as the superposition of specific amounts of each natural mode, the modal information can be extracted using established frequency response techniques.

The disturbance used in these tests was an impulse of steer torque, as had been used previously by Eaton (1973) and Verma (1978). The properties of this type of disturbance are discussed in detail subsequently.

In the present tests, the rider was required to ride the motorcycle at constant speed with his hands off the handlebars. To enable this a throttle locking device was used to maintain the required speed. The rider was instructed to

(i) bring the cycle to the test speed while travelling in a straight line;

(ii) remove his hands from the handlebar to eliminate any steering inputs;

(iii) ensure that the cycle was still travelling in a straight line;

(iv) hit one side of the handlebar with a clenched fist so as to impart a force for as short a duration as possible.

The cycle was then allowed to move, without control, until all obvious vibrations had ceased, or, for at least 5 seconds after the initial blow. Naturally, if a fall was imminent, control of the cycle was to be quickly regained.

The test speed was initially 80 km/h and was decremented in 10 km/h steps after several runs at each speed were attempted. The lowest test speed attempted was 27 km/h. For speeds lower than this, testing became dangerous. Note that if the cycle did not move in a straight line when the rider let go of the handlebars, he would move his body laterally on the seat until this straight-line trim condition was achieved.

As with the steady state turn tests, no form of rider lean restraining device was used. The rider, once again, was instructed to try to maintain his body in the plane of symmetry of the motorcycle.

The following rider/cycle variables were recorded:

- Steer Torque
- Steer Angle
- Roll Angle
- Yaw Rate (body fixed)
- Lateral Acceleration (body fixed)
- Rider Lean Angle
- Rider Twist Angle
- Forward Speed

Unfortunately, the torque transducer failed during the very first run so that no steer torque data for these tests are available. However, useful modal parameters can still be extracted from the remaining data.

3.4.3 Data Traces

Figures 3.16(a) to 3.16(h) show transducer outputs for two typical runs. The first was conducted at approximately 80 km/h (Figures 3.16(a) to 3.16(d)); the second at approximately 35 km/h (Figures 3.16(e) to 3.16(h)).

Figure 3.16(a) shows the variation of steer angle with time in response to the steer torque impulse. The response is a lightly damped, stable wobble oscillation of approximately 9 Hz. This lightly damped oscillation is also present on the other transducer outputs (Figures 3.16(b) to 3.16(d)), the relative amplitudes depending on the mode shape at the test speed. A low frequency oscillation of much smaller amplitude, and more heavily damped, can also be detected. The main indicator of this lower frequency oscillation is the asymmetry of the 9 Hz oscillation about the zero position on the transducer outputs.

For the lower speed (Figures 3.16(e) to 3.16(h)), the two frequencies of oscillation can be more readily seen. The high frequency oscillation (≈ 9 Hz) is assumed to arise from the wobble mode; that at the lower frequency (≈ 1 Hz) is assumed to correspond to the weave mode.

3.4.4 Extracting the Modal Information

By measuring the impulsive steer torque input and the various motorcycle responses, it had been hoped to measure complex frequency response functions by standard Fourier analysis techniques (Bendat and Piersol, 1971; 1980). For example, the magnitude and phase of the torque-to-roll frequency response function $H_T^{\phi}(f)$ could be obtained as

$$H_T^{\phi}(f) = \frac{G_{T\phi}(f)}{G_{TT}(f)} \tag{3.7}$$

where $G_{T\phi}(f)$ is the cross (energy) spectral density between the torque input and roll response and $G_{TT}(f)$ is the energy spectral density of the transient torque signal.

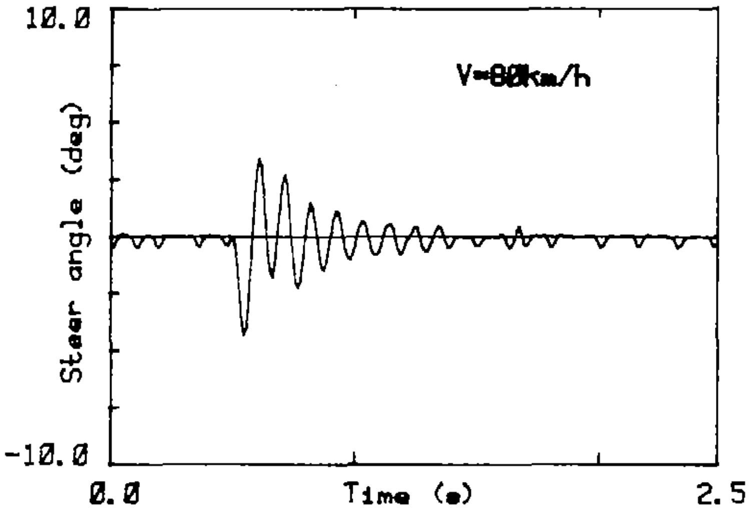

Figure 3.16 (a) Steer angle response to an impulse of steer torque.

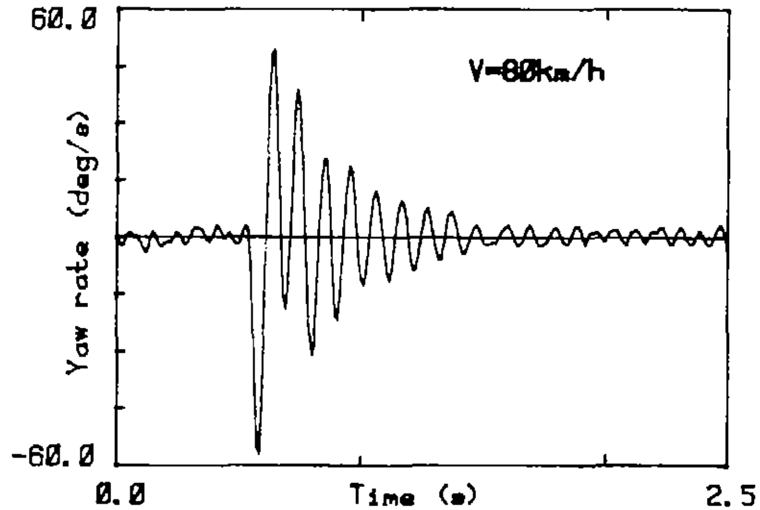

Figure 3.16 (b) Yaw rate response to an impulse of steer torque.

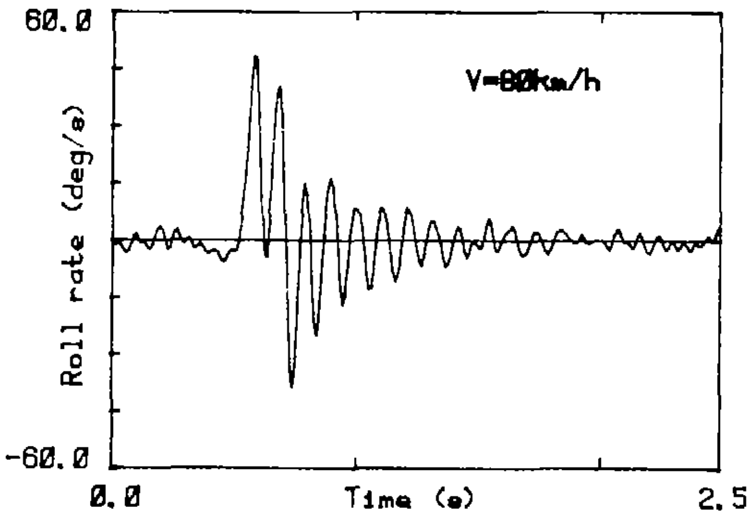

Figure 3.16 (c) Roll rate response to an impulse of steer torque.

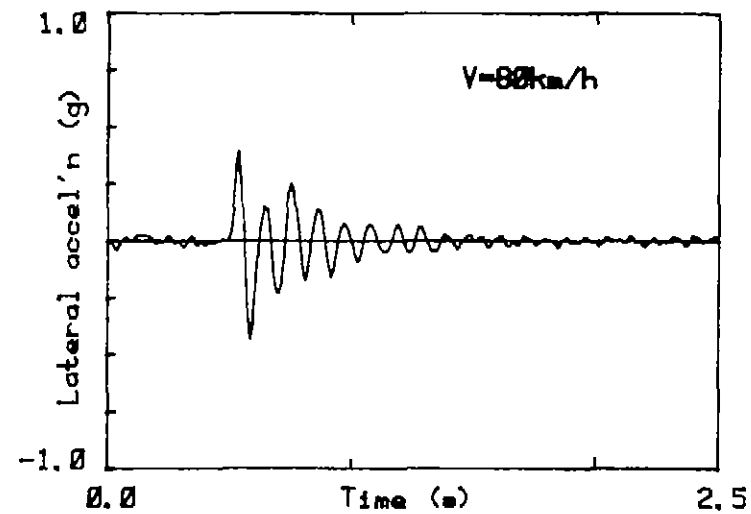

Figure 3.16 (d) Lateral acceleration response to an impulse of steer torque.

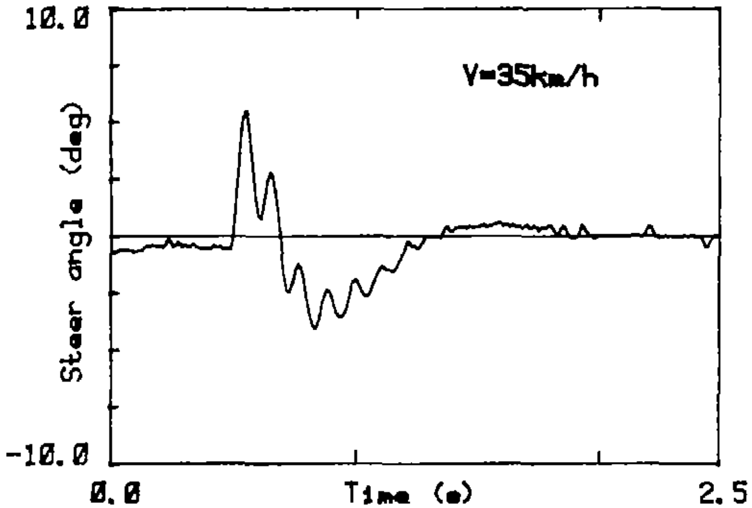

Figure 3.16 (e) Steer angle response to an impulse of steer torque.

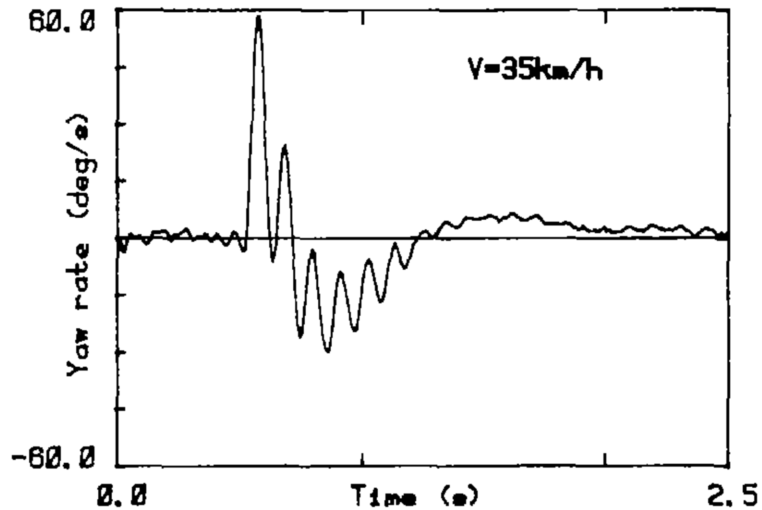

Figure 3.16 (f) Yaw rate response to an impulse of steer torque.

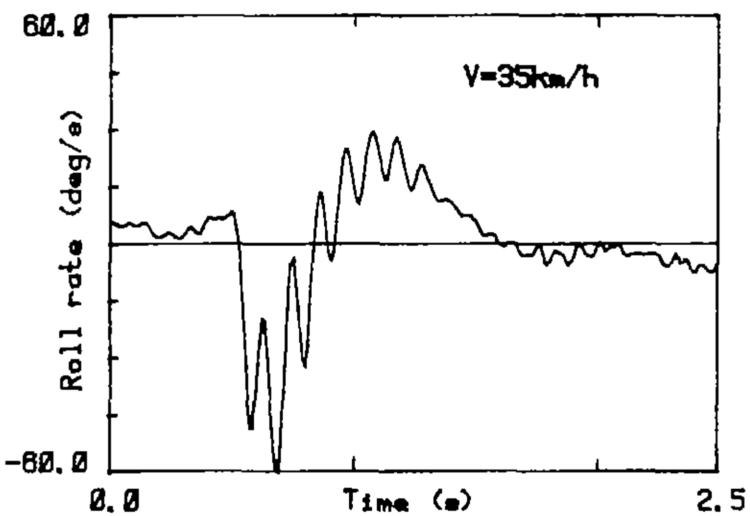

Figure 3.16 (g) Roll rate response to an impulse of steer torque.

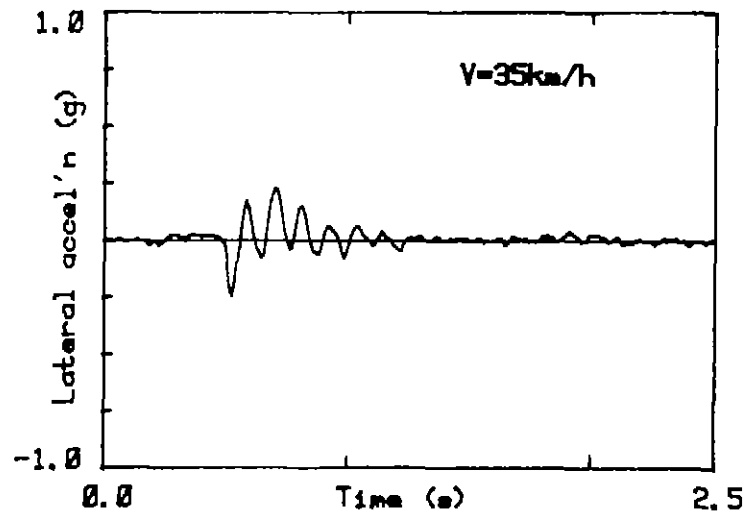

Figure 3.16 (h) Lateral acceleration response to an impulse of steer torque.

Unfortunately, the torque transducer failed during the first test of this series, a fact which did not become evident until the data were analysed at a later date, so that equation (3.7) could not be evaluated. The characteristics of an impulsive input are such, however, as to allow some recovery from this situation. An alternative expression of the input-output relationship of a system is

$$G_{\phi\phi}(f) = |H_T^{\phi}(f)|^2 G_{TT}(f), \qquad (3.8)$$

where $G_{\phi\phi}(f)$ is the energy spectral density of the transient roll response. The spectrum of an ideal (physically unrealizable) impulse has a constant value for all frequencies. Hence, from equation (3.8), the spectrum of the response to an ideal impulse is simply proportional to the squared-magnitude of the frequency response function. No phase information is available from this procedure.

The experimental torque pulses were not, of course, ideal impulses. However, the proportionality relationship would hold, over the frequency bandwidth of interest, provided the pulses were of sufficiently short duration. The duration of the pulses is not known. From Figure 3.16(a), say, it can be seen that the pulse duration would be less than a quarter-period of the first oscillation, viz. 0.04 s. Verma (1978), using the same experimental technique, stated the pulse duration to be less than 0.02 s.

The frequency spectra of common test pulses are shown in Figure 3.17 (Doebelin, 1980), in which the magnitude of the Fourier transform has been normalized and the frequency (w) is expressed as a dimensionless ratio. (The Fourier transform is proportional to the square-root of the energy spectral density.) For an assumed pulse width (T) of 0.02 s, all of the possible idealizations of the actual torque pulses shown in the figure have a significant energy content over the frequency bandwidth of interest (approximately 10 Hz, or a non-dimensional frequency of 0.20). It would appear that the level of excitation at the wobble mode frequency (approximately 9 Hz) would have been somewhat lower than for the lower-frequency weave mode. However, as the wobble is quite lightly damped, the variation of the input spectral density over its narrow resonance bandwidth would be fairly small, enabling a reasonable measurement of the shape of the resonance peak.

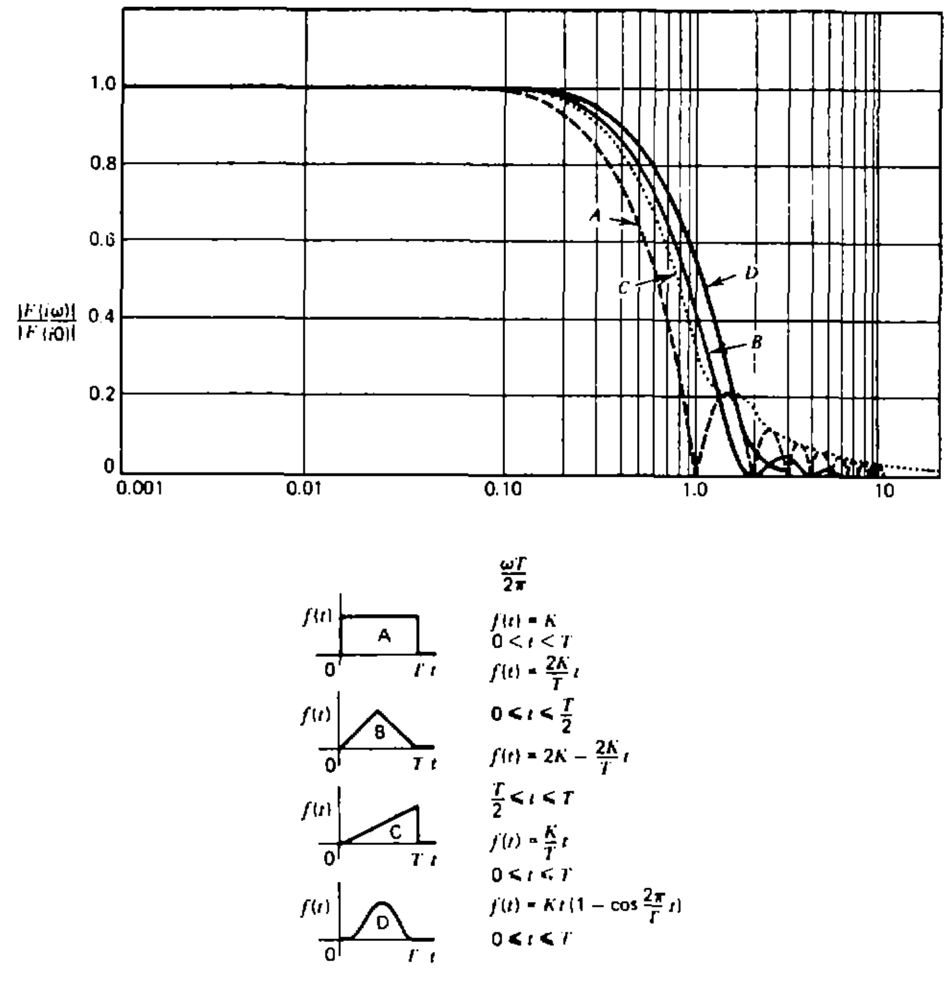

Figure 3.17 Frequency response spectra of common test pulses (Doeblin, 1980).

The technique used to extract the modal information, then, was to compute from a response trace, x(t) say, the energy spectral density $G_{xx}(f)$. From equation (3.8), the magnitude of the corresponding frequency response function could be taken as

$$|H_T^x(f)| \propto [G_{xx}(f)]^{1/2} \tag{3.9}$$

Figures 3.18(a) to 3.18(d) show the frequency response estimates corresponding to the data traces in Figures 3.16(a) to 3.16(d). Several runs were performed at each test speed; the frequency response functions for these runs were averaged before natural frequency and damping estimates were made.

As the frequencies of the weave and wobble modes were reasonably well separated, the modal parameters were estimated by curve-fitting an analytical expression for a single-degree-of-freedom response function to the measured response function over a narrow bandwidth centred on the peak response frequency for each mode: The response was assumed to be of the form

$$|H_T^x(f)|^2 = \frac{1}{G[(f_n^2 - f^2)^2 + 4\zeta^2 f_n^2 f^2]} = H^2, \text{ say,} \tag{3.10}$$

where G is a constant and f_n and ζ are, respectively, the undamped natural frequency and damping ratio of the mode. Rearranging equation (3.9) gives

$$1/H^2 = G[f^4 - 2f_n^2(1 - 2\zeta^2)f^2 + f_n^4], \tag{3.11}$$

which is of the form

$$Y = AX^2 - BX + C, \tag{3.12}$$

with $Y = 1/H^2$ and $X = f^2$. A least-squares fit of the quadratic expression (3.12) to the data in the vicinity of the natural frequency yielded estimates of A, B and C, from which the modal parameters were obtained as:

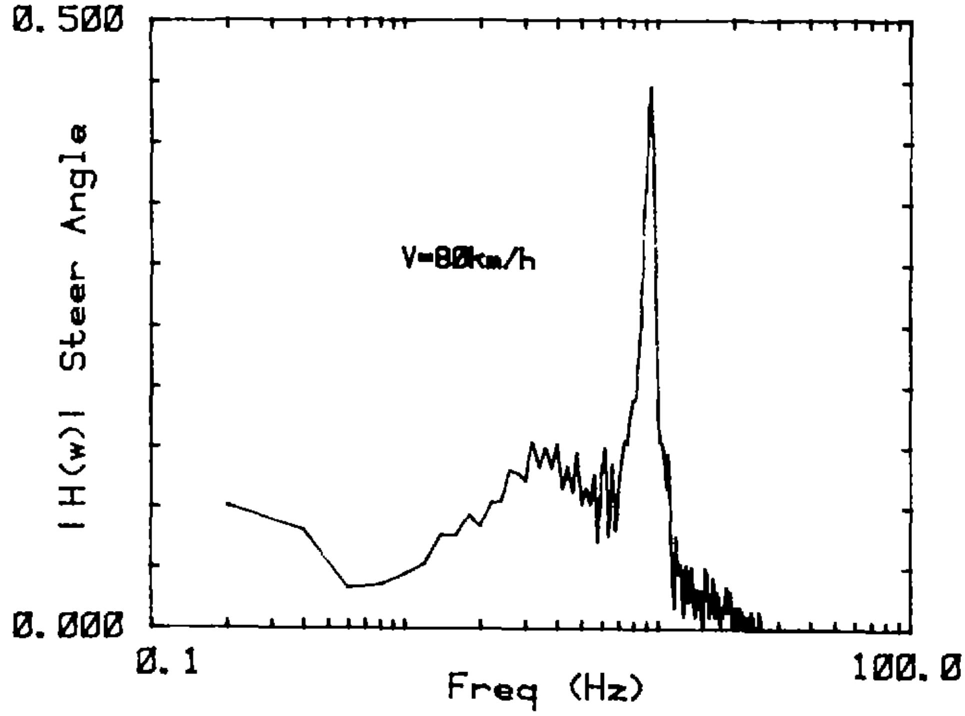

Figure 3.18 (a) Frequency response function for steer angle.

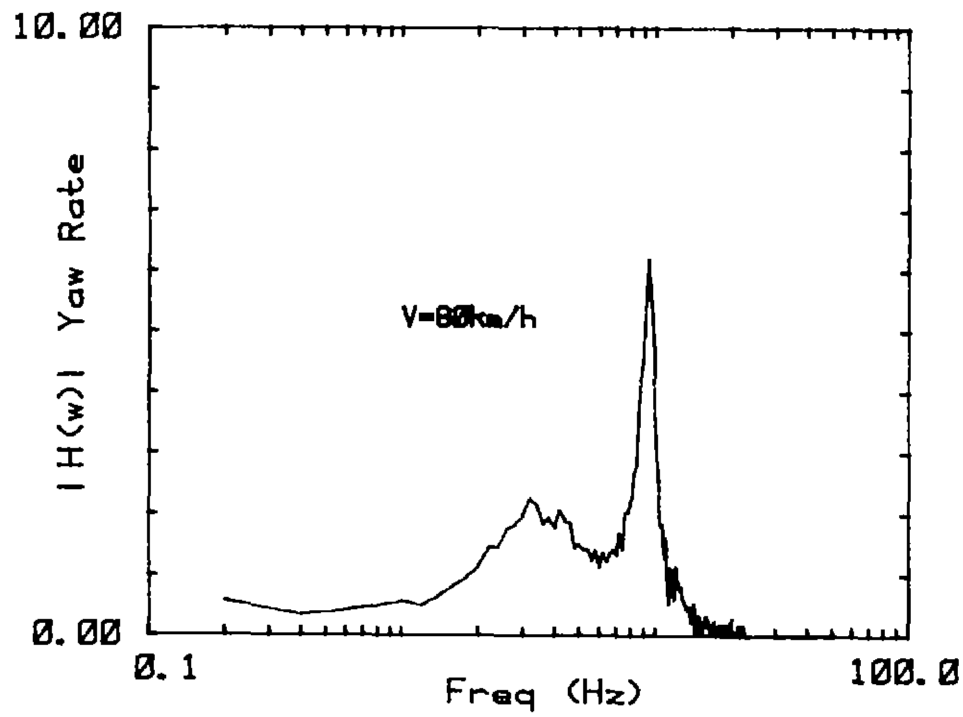

Figure 3.18 (b) Frequency response function for yaw rate.

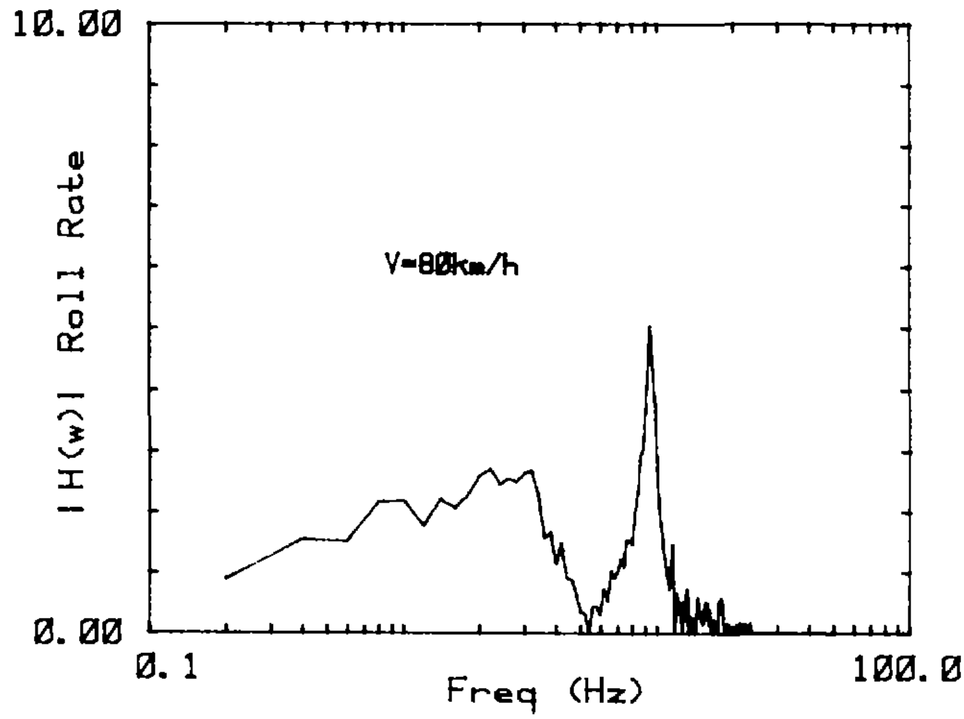

Figure 3.18 (c) Frequency response function for roll rate.

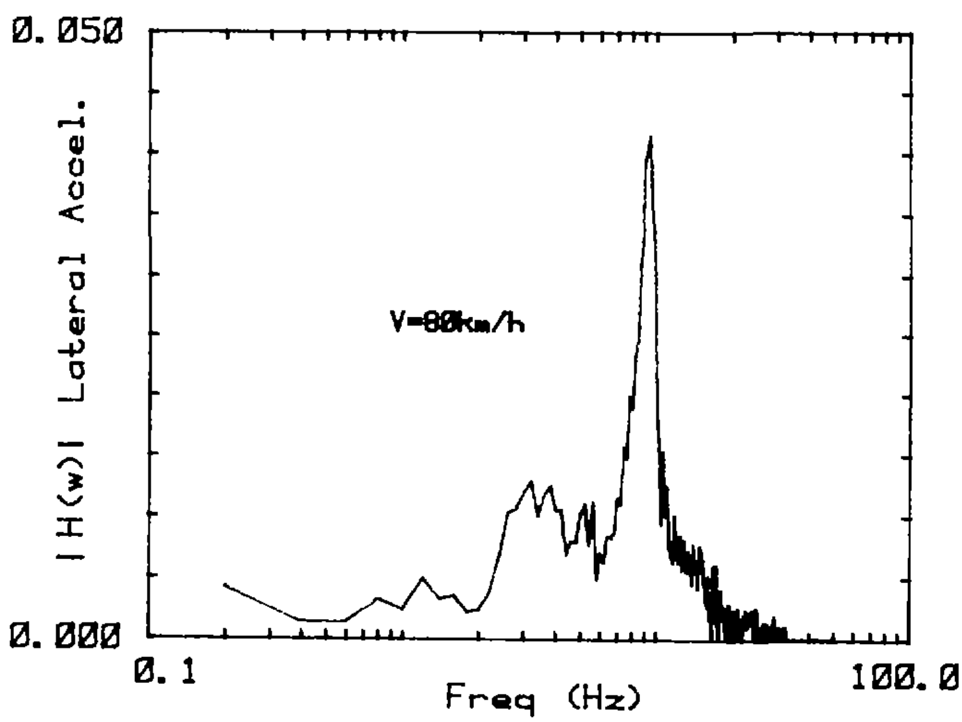

Figure 3.18 (d) Frequency response function for lateral acceleration.

$$f_n = (C/A)^{1/4}$$

$$\zeta = \left[\frac{1}{2} - \frac{B/A}{4f_n^2}\right]^{1/2} \qquad (3.13)$$

The procedure just described was considered more accurate than the traditional 'half-power bandwidth' method, or two-point methods (e.g. Verma, 1978), because it makes more use of the available data. An indication of how well the assumed response function represented the measured data could be obtained by varying the number of data points used in the curve-fitting process. For the weave mode, 9, 11, 13 and 15 points were used; 3, 5, 7 and 9 points were used for the wobble mode.

3.4.5 Results

Estimates of the natural frequencies and damping ratios of both modes derived from the steer angle, roll rate, yaw rate and lateral acceleration responses are shown as functions of forward speed in Figures 3.19(a) to 3.19(d). The multiple points plotted at each speed in these figures result from curve fits to differing numbers of data points.

All four response variables give consistent estimates for the wobble mode frequency, indicating a slow increase from about 8.7 Hz at 30 km/h to 9.4 Hz at 80 km/h. The wobble mode damping is quite light, the damping ratio reaching a minimum of about 3% of critical between 50 km/h and 60 km/h. As indicated previously, Eaton (1973) obtained qualitatively similar results for the Honda CL175.

The effect of speed on the weave mode frequency is more pronounced, increasing it from about 1 Hz at 30 km/h to 3.5 Hz at 80 km/h. The greater variability in the estimates of the weave mode parameters, particularly the damping, arises because the heavier damping of this mode produces a less well-defined resonance peak and a poorer signal/noise ratio. The fits to the steer angle and yaw rate data produced the most consistent estimates, indicating that the weave mode damping ratio reaches a maximum of about 0.6 at 45 km/h.

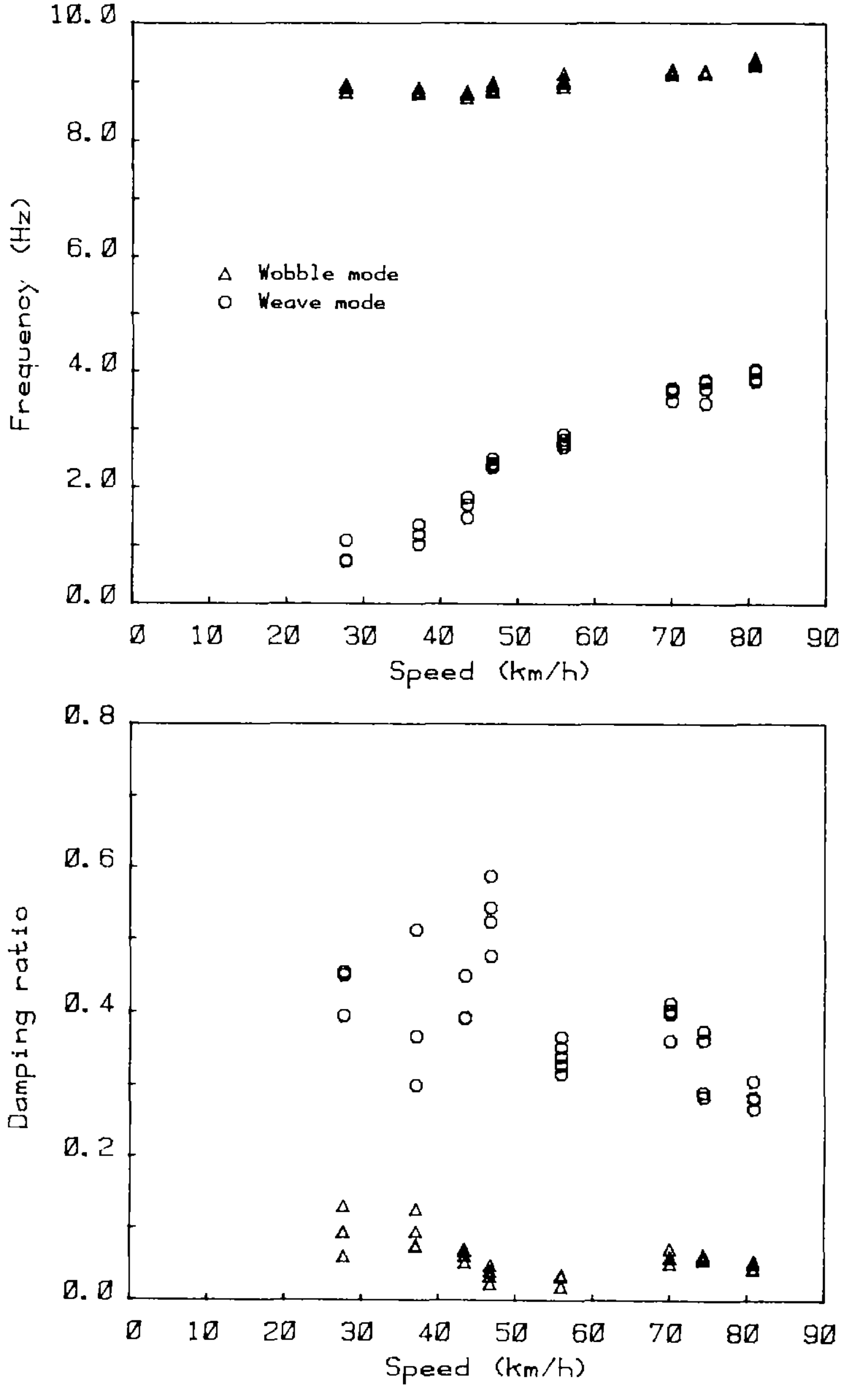

Figure 3.19 (a) Estimates of natural frequency and damping ratio as a function of speed using steer angle data.

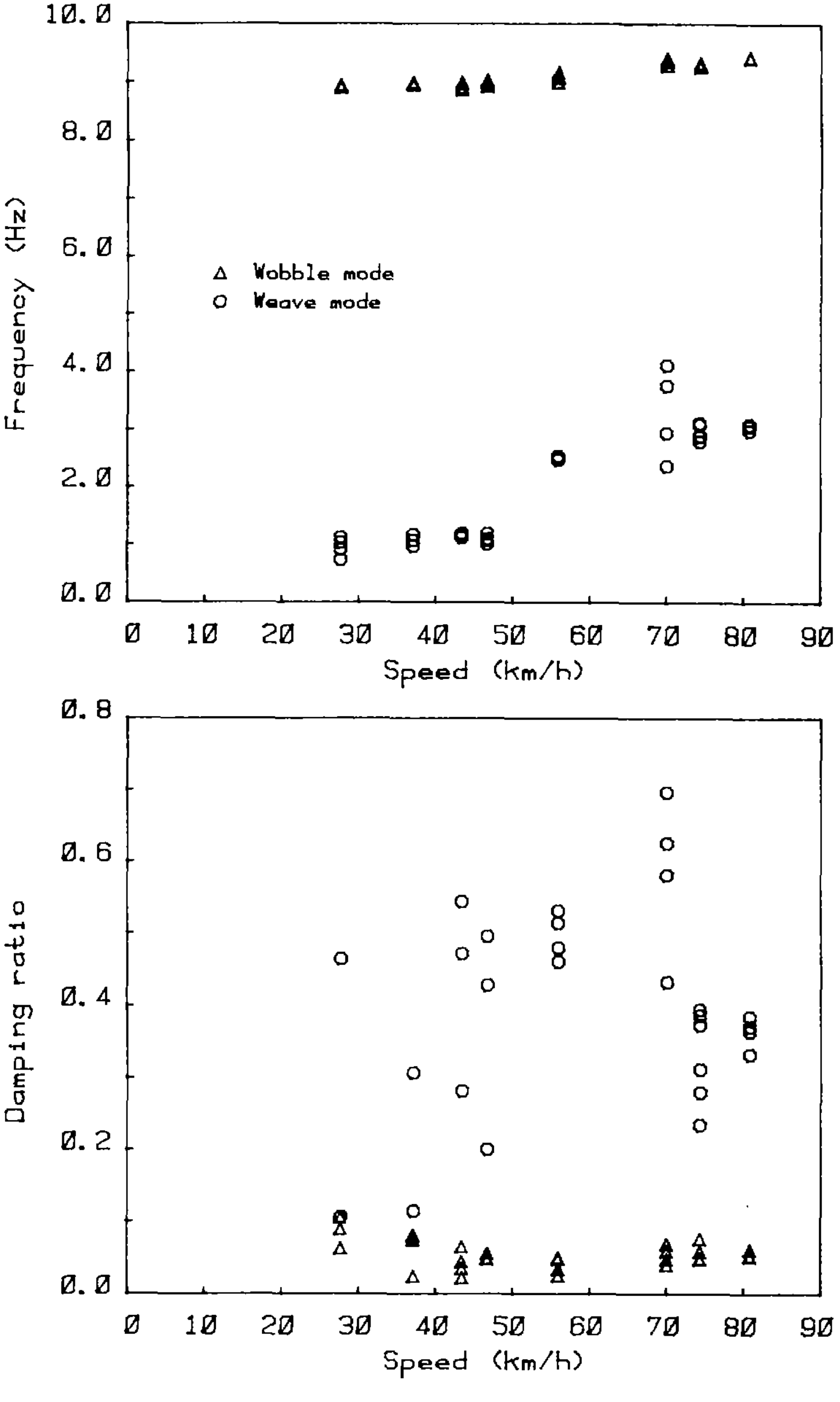

Figure 3.19 (b) Estimates of natural frequency and damping ratio as a function of speed using roll rate data.

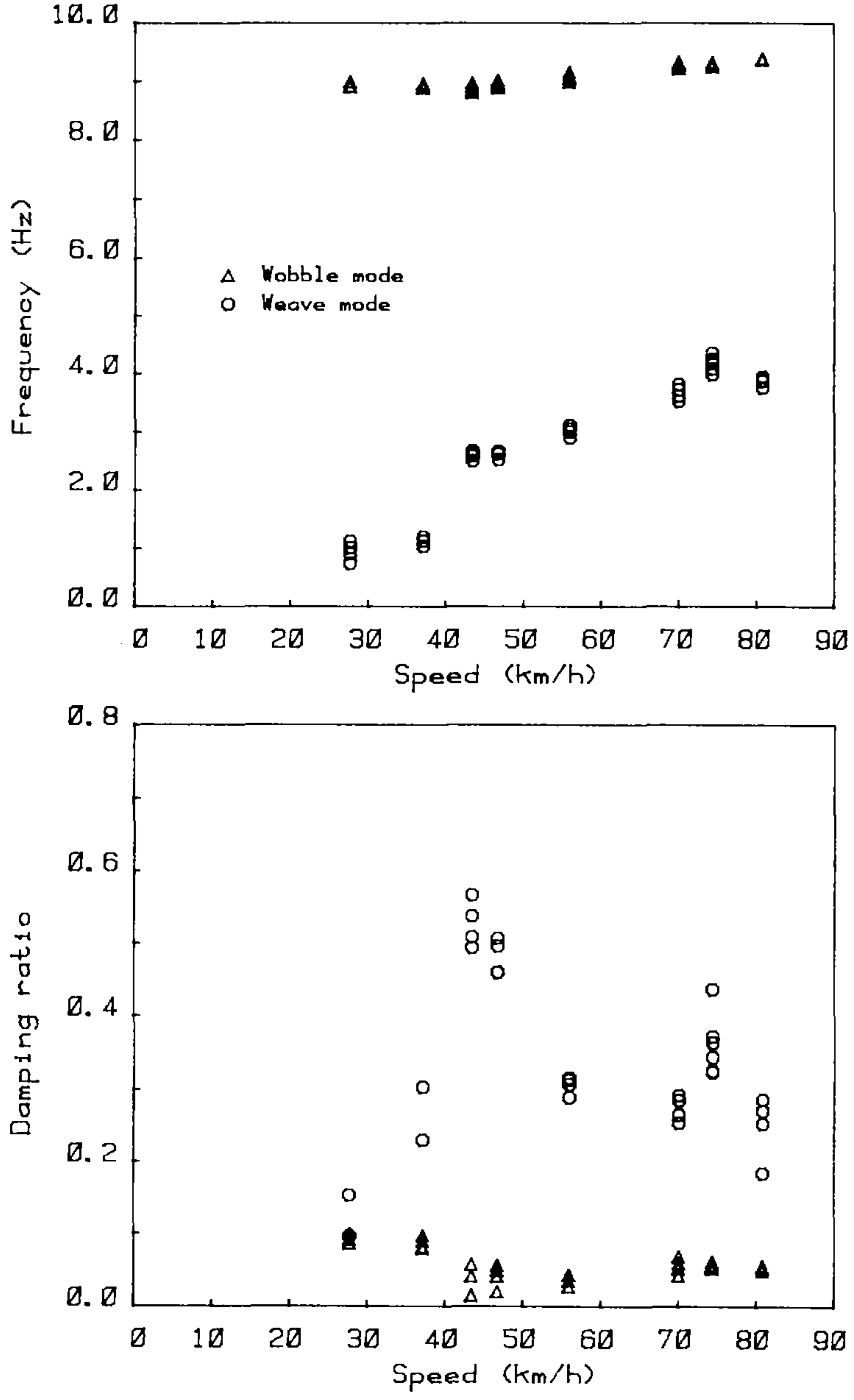

Figure 3.19 (c) Estimates of natural frequency and damping ratio as a function of speed using yaw rate data.

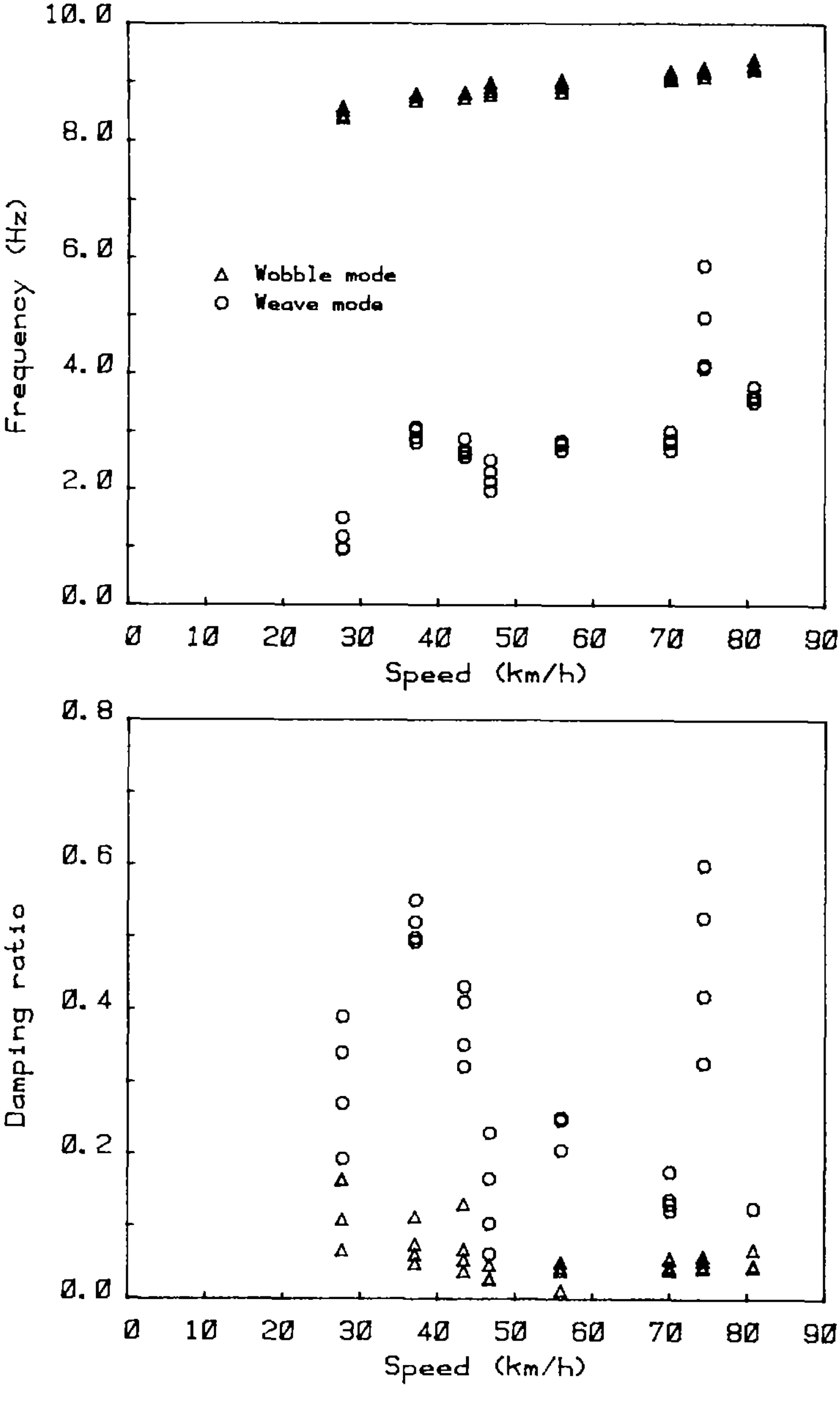

Figure 3.19 (d) Estimates of natural frequency and damping ratio as a function of speed using lateral acceleration data.

The trends in the present results may be compared with those obtained by Verma (1978) for a Honda CB750 in Figures 3.20 to 3.22. The speed range of the present tests is indicated in these figures. Verma's experimental results are indicated by the shaded areas: scatter was a problem here too. The solid and broken lines represent the predictions, respectively, of a four-degree-of-freedom analytical model and an eight-degree-of-freedom model in which frame flexibility effects are accounted for. It should be noted that Verma was unable to excite a measurable weave mode oscillation over most of the present range of test speeds.

Verma's wobble mode data show identical trends to the present results: a very small increase in natural frequency over the present test speed range and light damping, reaching a minimum at about 40 mph (65 km/h). The simulation results, which for the other modal parameters are in good agreement with the experimental results, are poor predictors of the observed wobble mode damping. Verma investigated several explanations for this discrepancy, the most favoured being that tyre non-uniformities could excite a forced oscillation of the wobble mode when the wheel rotational speed coincided with the wobble mode natural ferquency. For Verma's motorcycle this would occur between 30 to 40 mph, near to where the 'dip' in the damping ratio curve was found. However, this does not appear to be an adequate explanation of the discrepancy between the analytical predictions of the wobble mode damping of around 20% and 30% of critical and the identified values around 3% at 40 mph. For forced oscillations to produce such a dramatic change in the response spectra would require that the forced component of the response at 40 mph be large compared with that due to the torque pulse. If this were the case, and the wobble mode damping ratio was actually 0.2 - 0.3, then significant peaks at the forcing frequency would be observed in the response spectra at other test speeds. The forced oscillation would also be evident in the response time histories before the application of the torque pulse. Such was apparently not the case in Verma's data; it certainly was not the case for the present experiments.

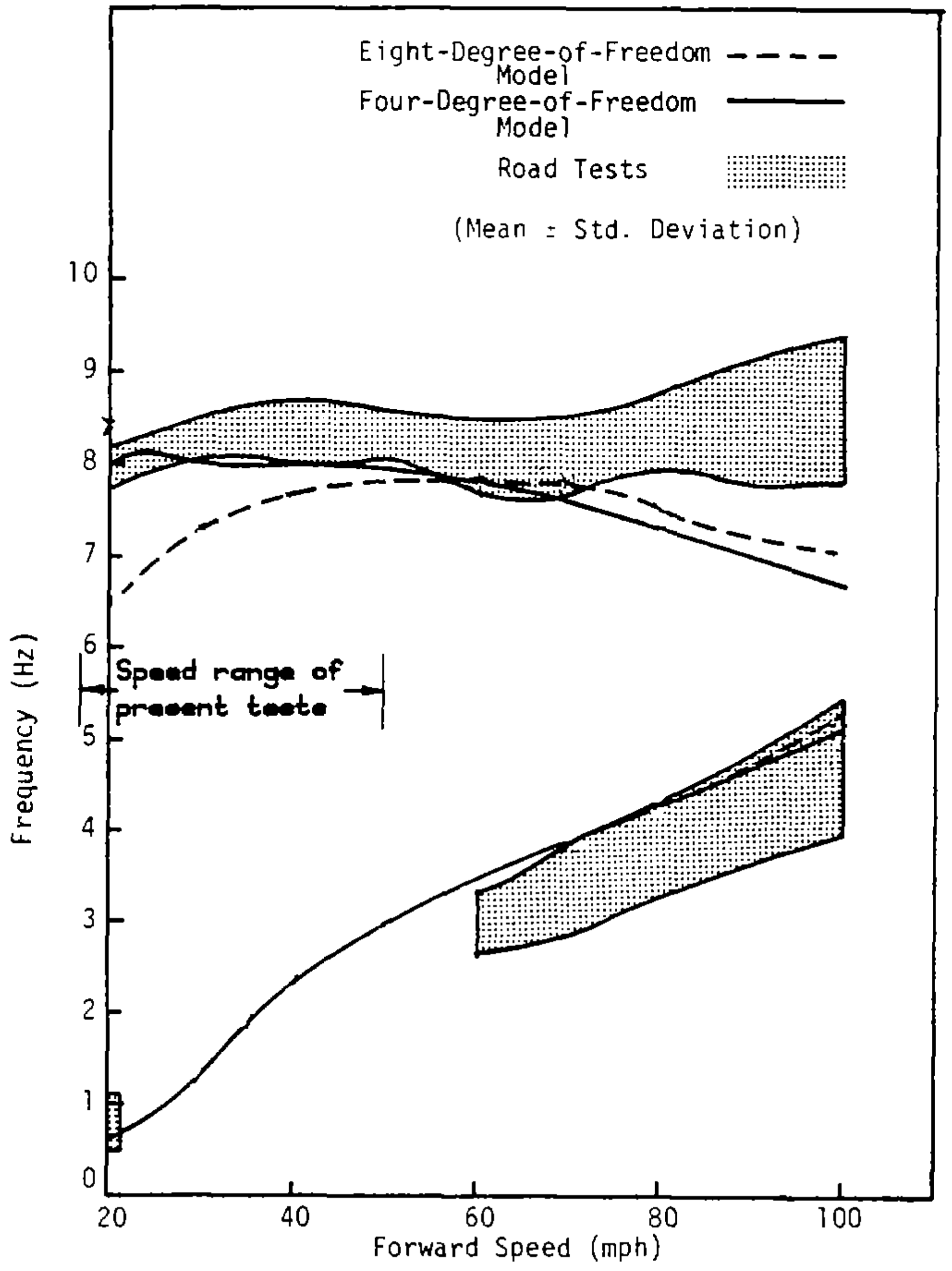

Figure 3.20 Comparison of theoretical and experimental weave and wobble frequencies of a Honda CB750 (Verma, 1978).

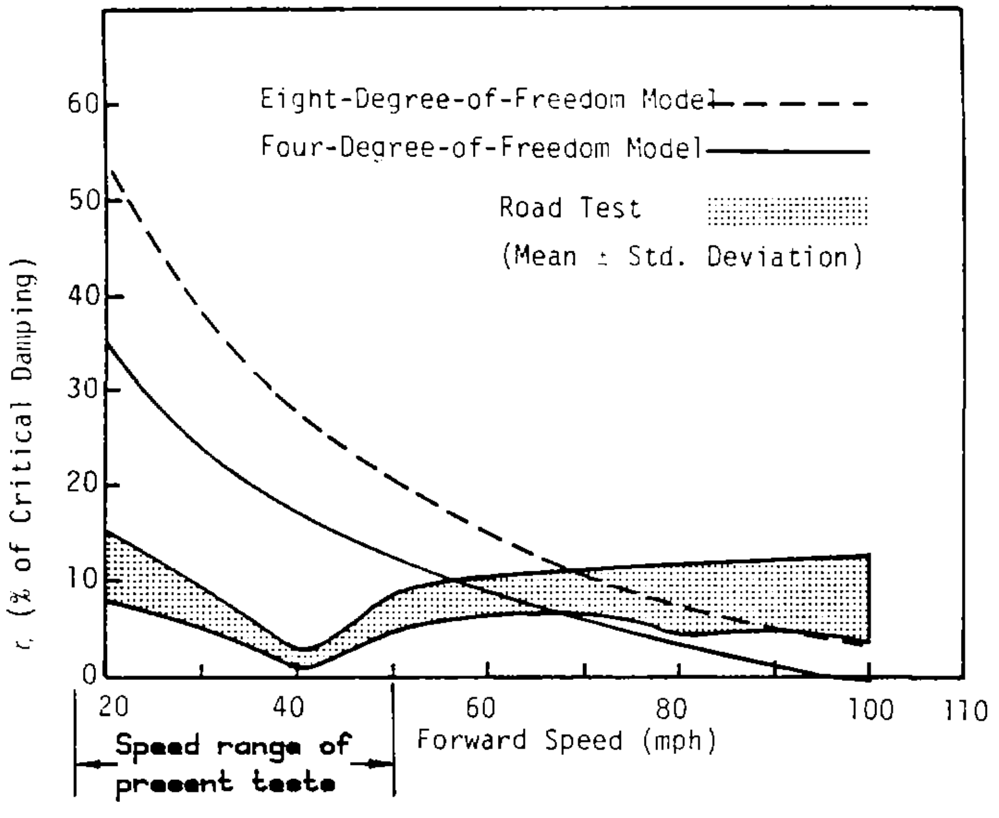

Figure 3.21 Comparison of theoretical and experimental wobble mode damping ratio for Honda CB750 (Verma, 1978).

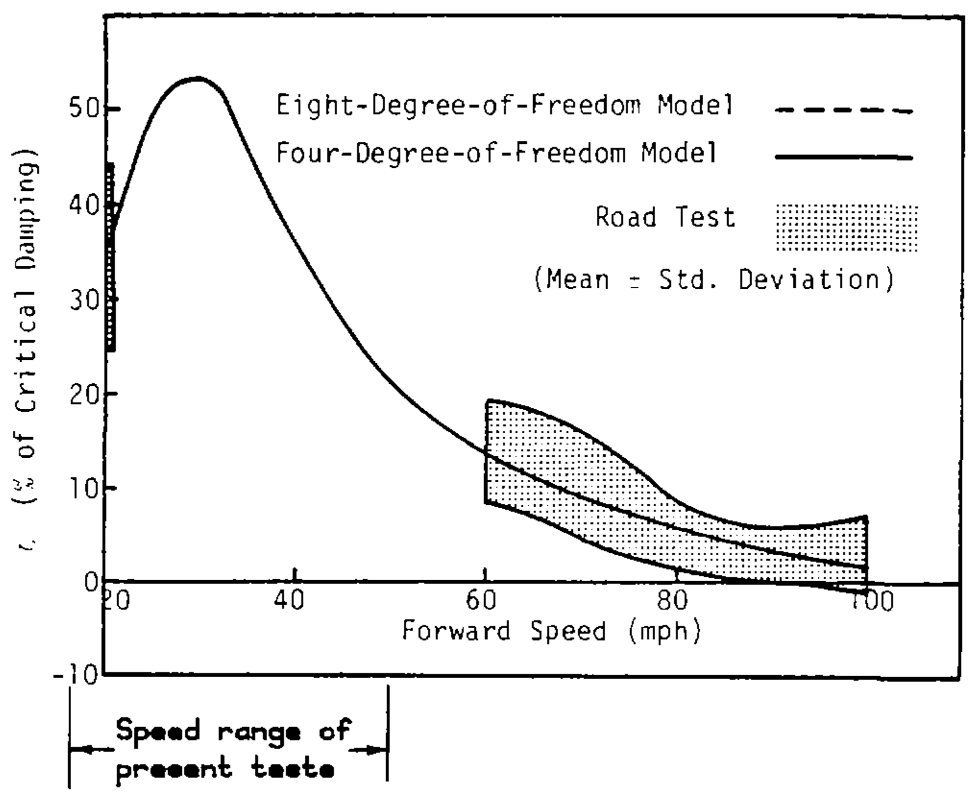

Figure 3.22 Comparison of theoretical and experimental weave mode damping ratio for Honda CB750 (Verma, 1978).

Verma's simulation prediction for the weave mode frequency and damping are confirmed by his experimental data at the speeds at which he could measure an oscillation. For the present range of test speeds, the simulation results shows precisely the same speed effect as in the present experimental results, the frequency increasing with speed and the damping reaching a maximum at about 30 mph (48 km/h).

The results for both the weave and wobble modes show a remarkable similarity in the dynamic modes of the two test motorcycles (which differ substantially in size, mass, tyres, etc).

3.4.6 Significance of Results in Relation to Rider Control

The frequency of the wobble mode is such that it is well outside the frequency range of rider control (about 1.6 Hz according to Weir (1972)). Although the damping of this mode is light, during normal riding a somewhat higher damping ratio could result from the energy dissipation in the rider's arms as a consequence of his grasping the handlebars. The magnitude of the change has not been explored here, nor is the author aware of any work conducted elsewhere covering this point. For 'normal', low-frequency rider control inputs the wobble mode is not expected to be a problem; however, rapid rider control inputs or external disturbances could excite a lightly-damped oscillation.

On the whole, the weave mode natural frequency is also beyond the range of active rider control. Rider control of the roll motion of the motorcycle will, however, affect the frequency and damping of the closed-loop 'weave mode'. As the open-loop mode is well damped, it would seem that there should be no control or stability problems associated with the weave mode for this test motorcycle.

3.5 CONCLUSIONS

(i) Steady state turn tests have shown that the steer torque requirement to maintain a steady turn of the test motorcycle (a Honda CB400T) was insensitive to lateral acceleration above about 0.2g, and fairly constant over the 20 to 80 km/h test speed range. The sense of the steady steer torque was consistently in a direction opposite to the direction of turn.

(ii) As a result of the nonlinear relationship between the steer-torque and lateral acceleration, the steady-state torque-input control gains varied somewhat with lateral acceleration at a given speed.

(iii) The Yaw-rate/steer-angle gain, by contrast, was independent of lateral acceleration.

(iv) The test motorcycle was oversteering, with a 'critical speed' of about 87 km/h.

(v) The steady-state response parameters measured for a variety of motorcycles with presumably 'acceptable' handling characteristics can be substantially different.

(vi) Impulse response tests yielded estimates of the natural frequencies and damping ratios of the weave and wobble modes of the test motorcycle which are in close agreement with Verma's (1978) data for a Honda CB750.

(vii) The test motorcycle appears dynamically 'well behaved', being open-loop stable at all test speeds and having a well-damped weave mode. The open-loop wobble mode is quite lightly damped; no closed-loop wobble problems were experienced, however.

CHAPTER 4

MOTORCYCLE OPERATOR SKILL TEST (MOST)

4.1 INTRODUCTION

The purpose of the first experiment was to investigate how riders performed the Motorcycle Operator Skill Test (MOST) developed by the National Public Services Research Institute (NPSRI) (1976). Subjects were required to ride the instrumented motorcycle (described in Appendix A) so that rider control as well as motorcycle response variables could be monitored and subsequently analysed.

In this chapter the individual MOST exercises are subjected to an 'item analysis' to determine their consistency and relative power as discriminators of riding skill. The performance criteria for some of the exercises are examined critically. Finally, the relationships between known characteristics of the riders and their performance on the MOST is investigated.

4.2 MOTORCYCE OPERATOR SKILL TEST (MOST)

The MOST is based on a 'Motorcycle Task Analysis' (MTA) (NPSRI, 1974) which gives an exhaustive inventory of performances, knowledges and skills required in the operation of a motorcycle (see Section 2.2.2 for more details). Each task in the MTA was assigned a "criticality" rating and only those performances strongly related to riding safety were considered for the MOST. The test is directed at measuring critical perceptual and perceptual-motor skills required in controlling the lateral and longitudinal motion of a motorcycle. The skills measured pertain to:

- Basic control operation
- Turning speed judgement
- Braking control
- Multiple turn control

Performance criteria are expressed in terms of observations which require neither interpretation nor inference on the part of the examiner. The test can be administered in the relatively short time of 10-15 minutes.

Much time and effort has been devoted to the development and assessment of the MOST as a licensing test (McPherson and McKnight, 1976; Anderson, 1978; Jonah and Dawson, 1979). Its applicability to the Australian scene is being considered by several state governments (RoSTA in Victoria, TARU in New South Wales).

At present there are two versions of the test: MOST and MOST II, the latter being a reduced version of MOST. Reduction became necessary since the paved area required by MOST is larger than that available to many licensing agencies. MOST II is also performed at lower speeds. However, it was decided to use the original MOST in this study since all of the initial evaluation work was performed on it, and a number of studies directed at validating it have been performed, the results of which can be used for comparison with the present data.

The test in its original form consists of 9 exercises, the easiest exercise being the first, and the most difficult the last. When a rider takes the test, penalty points are assigned for errors. If the rider accumulates more than a predetermined number of points the test is terminated and the rider is regarded as having failed. During its evaluation as a substitute for the present licensing test in California, it was found (Ford, 1980) that few applicants lost points on the first manoeuvre (starting and accelerating on a hill) and that tests 2-5 served the purpose of detecting the poorest riders before they reached the more hazardous tests. This was the basis for the decision made by the Californian Department of Motor Vehicles to omit exercise 1 from the skill test.

The remaining eight exercises are as follows:

(2) Sharp Turn
(3) Accelerating in a Turn
(4) Slowing in a Turn
(5) Normal Stop
(6) Turn Speed Selection
(7) Quick-Stop Straight
(8) Obstacle Turn (Left/Right)
(9) Quick-Stop Curve

Appendix F gives a description of the performance requirements, scoring criteria and penalty points for each exercise. The physical dimensions of the course are shown in Appendix D. Instructions given to the riders are reproduced in Appendix C.

4.3 SUBJECTS

A sample of 69 volunteer riders with a wide range of riding experience and (presumably) riding skills was recruited. Ten riders took part in a pilot experiment; the remaining 59 were subjects in the main investigation. Most subjects learned of the study through the Motorcycle Riders' Association (MRA), which took an early interest in the work. In an attempt to recruit more subjects with little riding experience, posters (see Appendix G) were displayed at the Motor Registration Branch licensing station in Carlton, Victoria. In the event, only a few subjects came from this source. The Victorian School of Motorcycling, however, provided 9 novice riders.

The sample was compared with statistical data in order to assess how representative it was of the general riding population. Population data were identified from licence details held by the Victorian Motor Registration Branch (MRB) and a survey of non-accident-involved South Australian riders (Johnston, Milne and Cameron, 1976).

The MRB data shown in Table 4.1 allow only very imprecise estimates of the riding experience of the population of Victorian riders. It would appear that roughly half of the 'authorized' rider population have a full licence, implying at least three years of on-road experience. A similar proportion (48 percent) of the present sample of riders reported having had 3 years or more on-road riding experience.

TABLE 4.1

MOTORCYCLING POPULATION IN VICTORIA, JANUARY 1981.

Permit category	Number	Percentages	
Probationary Licence (Learner Permit period plus 0-3 years)	24122	30.4%	22.9%
Full Licence (Learner Permit period plus 3 years or more)	55216	69.4%	52.3%
Learner Permits (issued in 1980*)	26207	-	24.8%
'Total riding' population+	105545	100.0%	100.0%

Source: Motor Registration Branch

* this includes learners with a 12 month permit and 3 month extension.

\+ this is an overestimate since some of the learner riders probably obtained a probationary licence during 1980.

The only known source of detailed survey data was the paper by Johnston et al. (1976). Figures 4.1 to 4.3 compare their results for experience (in terms of years ridden), engine capacity and rider age with the present sample. Since the licensing age in South Australia is 16, the data in Figure 4.3 do not include riders of the ages 16 and 17, who represent 9% of the total non-accident sample. For the data in Figures 4.1 and 4.2 it was not possible to determine the contribution to engine capacity and experience made by the young riders. From Figure 4.1 it appears that the distributions of riding experience are quite similar, with the present study sample being somewhat less experienced.

Figure 4.2 shows that the present study group tend to ride larger capacity motorcycles than the South Australian sample. The earlier licensing age in South Australia could partly explain this result since it might be expected that riders in the 16 - 17 year age group would be less financially able to purchase, maintain and run a large motorcycle. This however could account for, at most, 9% of the difference.

Figure 4.3 and Table 4.2 show the present study group to be marginally less than Johnston et al's. The difference in licensing age could again contribute to this result.

TABLE 4.2

MEAN AND MEDIAN AGE COMPARISONS

	Median age	Mean
Present study	22.4	26.7
Johnston et al (1976)	22.7	*
McPherson and McKnight (1976)	22	23.06

* Could not be determined from data given in report

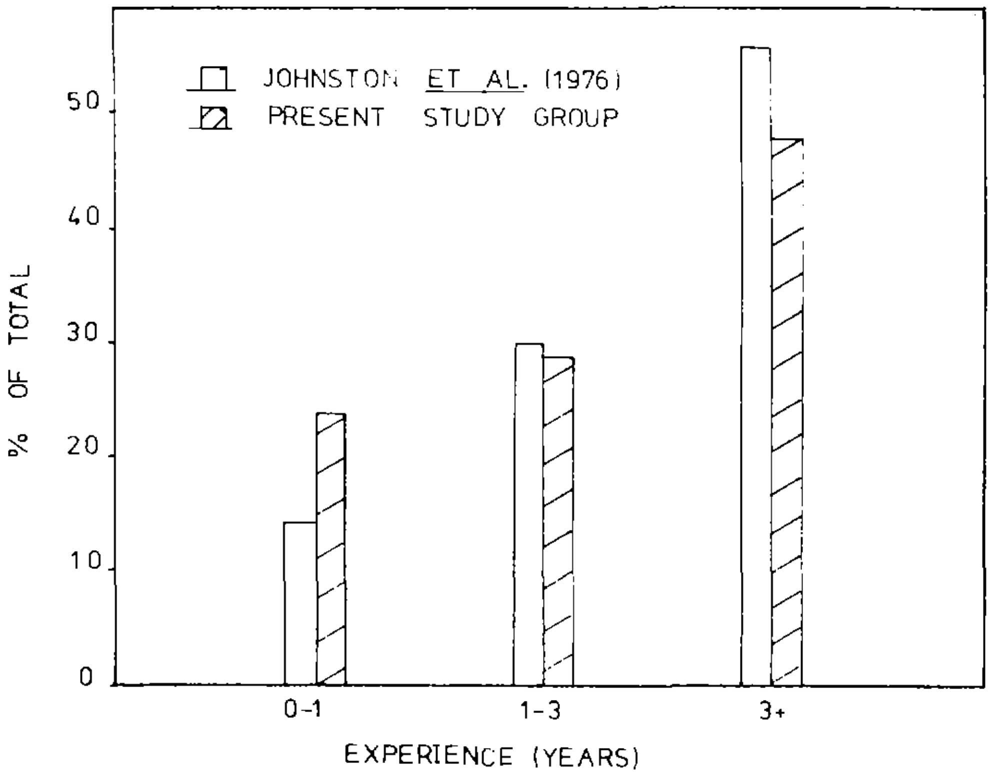

Figure 4.1 **Comparison with South Australian riding population (taken from Johnston et al., 1976): Total riding experience in terms of years riding.**

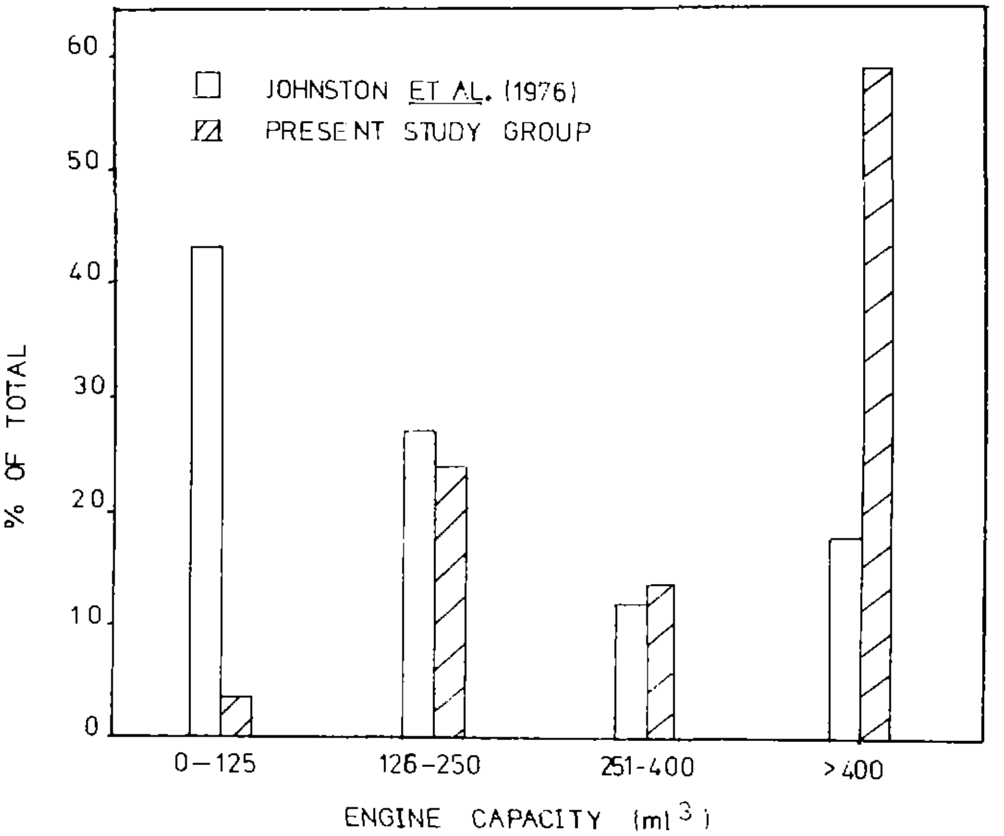

Figure 4.2 **Comparison of engine capacities of motorcycles ridden.**

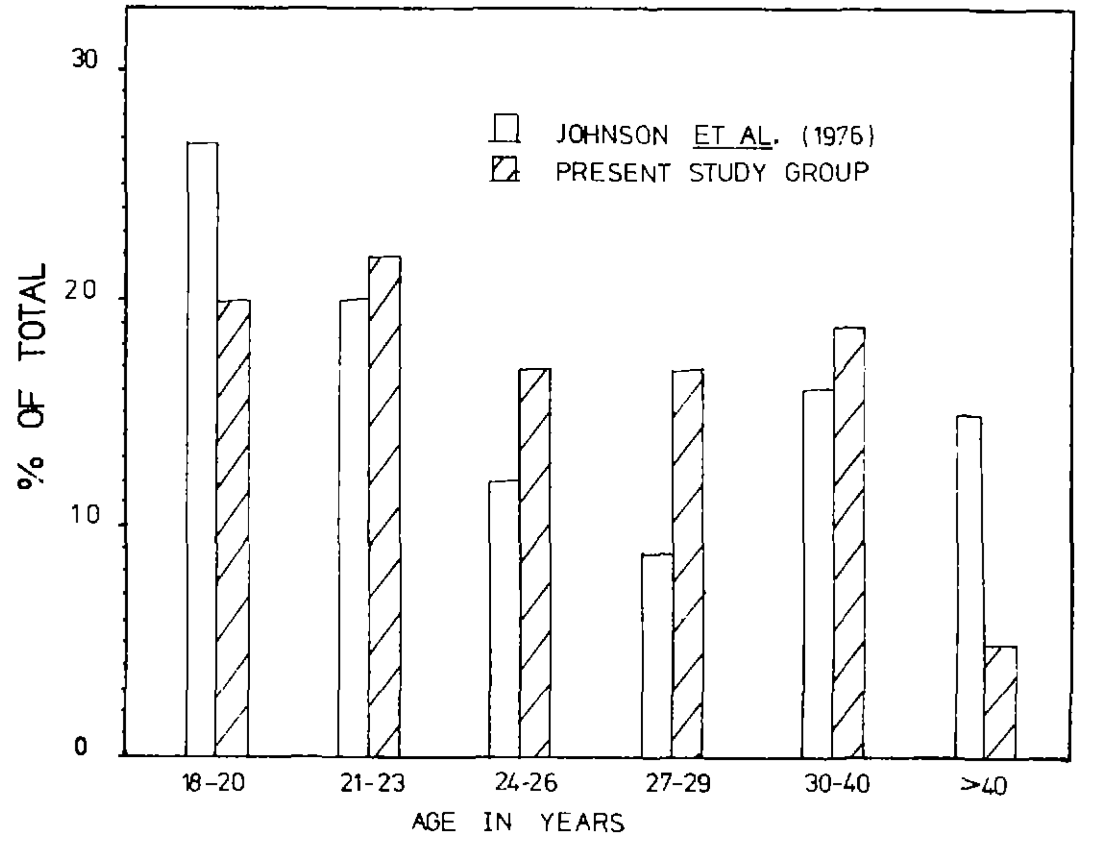

Figure 4.3 Age comparison.

On the whole, these comparisons suggest that the present group of riders is reasonably representative of the population of riders, in terms of age, experience and motorcycle size, except for the extremes of engine capacity. It should be noted, however, that it was not intended that the present sample should be closely representative of the riding population. Rather, a wide range of skills, reasonably uniformly distributed, was the main requirement.

4.4 MOST SET-UP

A site large enough to accommodate the test exercises and provide the necessary safety zones (see Appendix D) was located at the Army Trials and Proving Wing at Monegeetta. One of the bitumen surfaced areas, adjacent to the sand and mud mobility pits, provided sufficient area to accommodate the MOST.

The test course layout procedure prescribed by NPSRI (1975) was followed. The course was marked out with white chalk and then delineated with white waterproof P.V.C. tape. Appropriate signal lights and a speed timing device were built, while other equipment was available within the author's university department.

4.5 MOST ADMINISTRATION

During the early stages of the project contact was established with Mr. Ray Newland, who in the early 1970s was involved with a private motorcycle training school and has also been an instructor with the Motorcycle Safety Foundation in the U.S.A. At present he is running a Motorcycle training school at Moorabbin, Victoria. Mr. Newland's experience with the MOST was of great value and he provided valuable assistance during the initial pilot tests.

Pilot tests were run so that the MOST examiner (the author), could familiarize himself with the test administration and scoring procedures. It was thought that after 10 subjects had been tested, enough experience had been gained to administer the test in a uniform and objective manner.

Testing was only conducted when weather was fine and the test area dry.

Subjects generally had no prior knowledge of the tests to be performed. At the beginning of each day of testing, the group of riders to be tested were taken around the course, on foot, and verbally given details of each manoeuvre and the scoring criteria. Each rider was then given a copy of the 'Applicant Instructions' shown in Appendix C - which describes in more detail the test exercises and scoring criteria. In addition, prior to each exercise, the instructions shown in Appendix E were read to the rider.

In its normal application, MOST is terminated when riders lose a certain numbers of points (16, according to McPherson and McKnight, 1976). In this study, however, riders were required to complete the entire test regardless of how many points were lost, since the aim was to establish how riders of varying levels of skill performed in a series of tasks of graded difficulty. In addition it was envisaged that the more difficult exercises would be better discriminators of skill than the less difficult exercises.

After ensuring that a subject was familiar with the overall test, he or she was given the opportunity to ride the instrumented motorcycle until they felt sufficiently familiar and comfortable with the machine to perform the test. This decision was left to the rider and familiarization times varied from 1 to 15 minutes. Riders were not permitted to ride on the actual course during familiarization, so as to prevent possible performance variations due to learning.

Most subjects were initially apprehensive about riding the instrumented motorcycle (shown in Figure A.1). However, after some reassurance and the familiarization run, confidence was restored.

Following completion of the test, riders were not told their score, so as to avoid influencing other riders waiting to take the test.

4.6 ANALYSIS OF MOST SCORES

4.6.1 Introduction

The scores assigned to subjects in the MOST are investigated in this section. The mean scores assigned for each exercise, and the mean scores assigned for the associated performance criteria for each exercise, are examined to determine which features of the test accounted for the highest point loss. The rider sample was then divided into two, on the basis of score, and the analysis repeated to determine which aspects of the test discriminate best between the low and high scoring subjects. Since points were assigned for errors, the low scoring subjects were, according to the test, the more skilled riders, and the high scoring riders the less skilled. The usefulness of each task as a skill discriminator was then examined by way of histograms of score frequency distributions, and by examining the correlations between the individual exercises, and each exercise and overall score.

4.6.2 Overall Scores

Tables 4.3 and 4.4 present the means, standard deviations and 90% confidence intervals for the total score and the various performance criteria for each exercise, for the present study group. For easier comparison these are shown plotted in Figure 4.4. It should be noted that these scores represent points assigned due to errors. Therefore, the higher the score the poorer the performance on the test. The mean scores obtained subsequently reflect the task difficulty. It can be seen from Figure 4.4 that the first 5 exercises are the easiest and the last 3 exercises are progressively more difficult.

TABLE 4.3

STATISTICS OF MOST EXERCISE SCORES

Exercise	Mean	Standard deviation	90% confidence interval for mean
2	0.69	1.70	0.32,1.06
3	0.59	1.37	0.29,1.58
4	1.22	1.64	0.86,1.58
5	0.74	1.71	0.37,1.11
6	0.88	1.99	0.45,1.31
7	1.49	2.25	1.00,1.98
8	2.29	2.51	1.74,2.84
9	3.78	2.20	3.30,4.26
Overall	11.70	7.89	9.98,13.42

The statistical significance of the difference between the mean scores (2-tailed t-test) for exercises 2 to 9 is shown in the following tabulation, where ** denotes p<0.01, and * denotes p<0.05 :

	3								
	4		*						
	5								
Exercise	6								
	7	*	**		*				
	8	**	**	**	**	**	*		
	9	**	**	**	**	**	**	**	**
		2	3	4	5	6	7	8	9

Exercise

TABLE 4.4

STATISTICS OF MOST EXERCISE SCORES BY SCORING CRITERIA (N = 59)

Exercise*	Mean	Standard deviation	90% confidence interval for mean
2. Sharp Turn			
a. Path	0.64	1.66	0.28,1.00
b. Feet	0.05	0.22	0.00,0.10
3. Accelerative Turn			
a. Path	0.34	1.04	0.11,0.57
b. Time	0.25	0.86	0.06,0.44
4. Decelerative Turn			
a. Path	1.03	1.55	0.69,1.37
b. Time	0.17	0.59	0.04,0.30
5. Stopping Judgement			
a. Skid	0.41	1.04	0.18,0.64
b. Stop	0.34	1.27	0.06,0.62
6. Turning Speed Judgement			
a. Path	0.25	1.11	0.01,0.49
b. Time	0.63	1.43	0.32,0.94
7. Quick Stop: Straight			
Distance	1.49	2.25	1.00,1.98
8. Obstacle Turn			
Course	2.29	2.51	1.74,2.84
9. Quick Stop: Curve			
a. Path	0.41	1.04	0.18,0.64
b. Distance	3.36	2.17	2.89,3.83
Total points deducted	11.70	7.89	9.98,13.42

* Details of the exercises and scoring criteria are given in Appendix F.

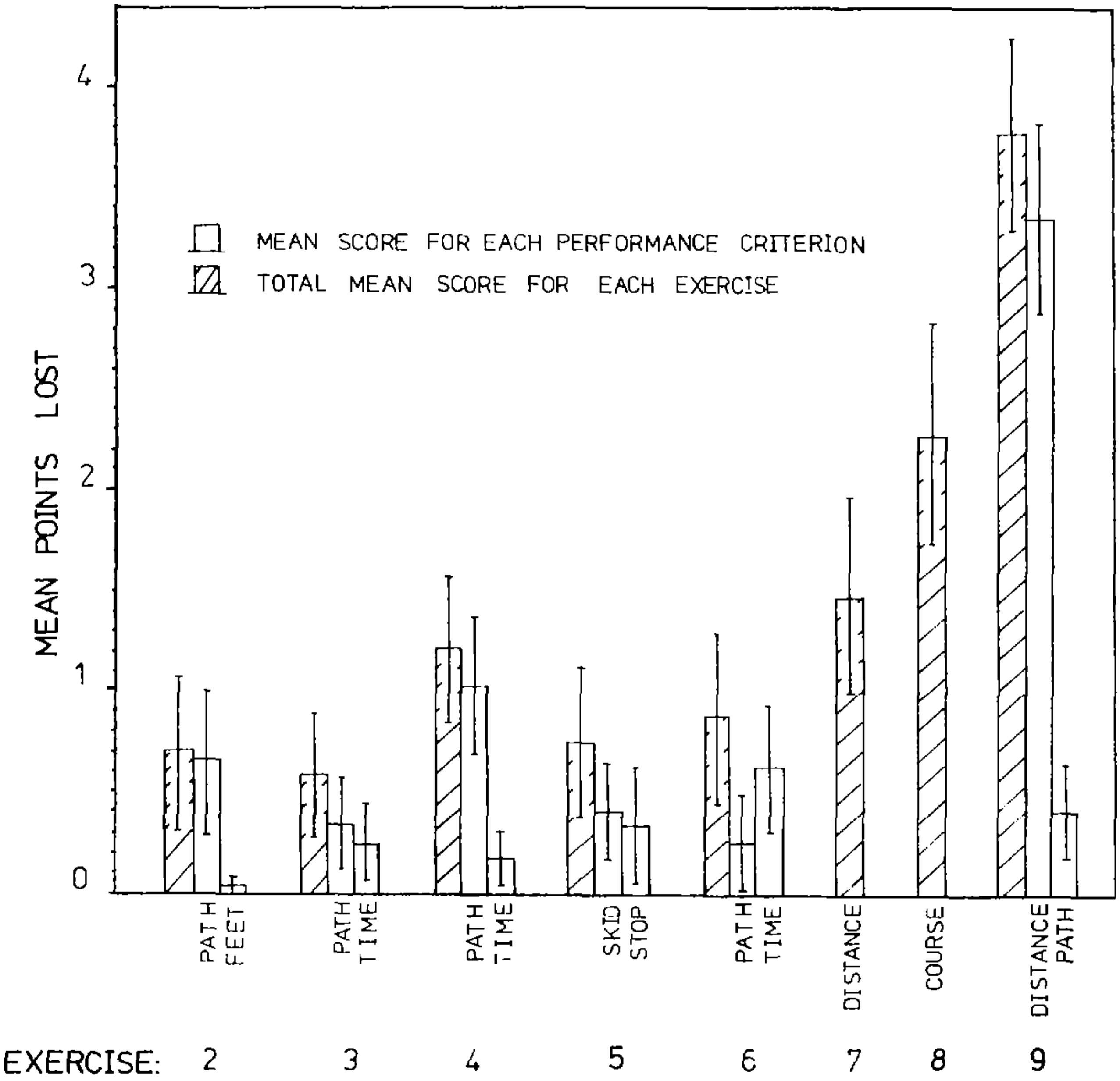

Figure 4.4 Score means and 90% confidence intervals of each exercise and the exercise performance criteria.

Thus, at the 0.01 level of significance, the exercises with a mean score higher than at least one of the other exercises are:

7, Emergency Braking: Straight
8, Obstacle Turn
9, Emergency Braking: Curve

4.6.3 Scoring Criteria

A statistical test on the means (2-tailed t-test) for exercises with two scoring criteria (exercises 2, 3, 4, 5, 6 and 9) was performed to determine which criterion was responsible for the greater loss of points. The means for the following criteria were found to be higher for $p<0.01$: Path errors for exercise 2 and 4, distance errors for exercise 9. Path and time error means were found to be no different for exercises 3 and 6. Skid and stopped position errors were no different for exercise 5.

Since path errors are assessed identically for exercises 2, 3, 4, 6 and 9 a test on the mean path-errors was performed to determine which manoeuvre had the largest path errors. Exercise 4 was found to have a larger path-error score than exercises 3 ($p<0.01$), 6 ($p<0.01$) and 9 ($p<0.05$). A possible reason for the larger path errors in exercise 4 can be found by examining the behaviour of the capsize mode during acceleration and deceleration. Recall from Section 2.4.2 that acceleration was found to improve the stability of the capsize mode while deceleration made it worse. The effect was particularly pronounced for a speed of 10 m/s (36 km/h). The reduced stability of this mode during deceleration would impose an extra workload on the rider, i.e. the motorcycle would be more difficult to control. Consequently, poorer path following performance would occur during deceleration than during acceleration or while travelling at a constant speed.

Time errors for exercise 6, 4 and 3 were next analysed. Time errors for exercise 6 were found to be higher than those for exercise 4 only ($p<0.05$).

4.6.4 Left/Right Bias

Exercise 8 was analysed to determine if there were performance differences between the left and right-hand obstacle avoidance manoeuvres. Only those riders who performed the manoeuvre over the correct speed range were considered. Five riders of the sample lost points on exercise 8 due to speed errors (i.e. going too slow). Of the remaining 54, 30 were required to perform a left-hand manoeuvre and 24 a right-hand manoeuvre. Nineteen of the 30 succeeded in the left-hand manoeuvre, whereas 13 of the 24 succeeded in the right-hand manoeuvre. Although a larger proportion of riders succeeded in the left-hand obstacle turn (63%) than the right-hand turn (54%), a statistical test concerning proportions indicated the difference was not significant. Further analysis showed that the mean speed at which the manoeuvre was performed was no different for the left- and right-hand turn groups and, there was no difference in the mean MOST score between the successful, or unsuccessful, left and right turn groups.

It is interesting to note that a similar bias was observed in the work of Goodrich (1971), in which a comparison of the manoeuvring capabilities of motorcycles and automobiles was investigated. Subjects were required to respond to a random combination of lights indicating whether an emergency braking, or a left or right divergent manoeuvre, was required. A lack of symmetry was observed in the ability of the motorcycle riders to manoeuvre to avoid a collision, the left-hand manoeuvre being more successful. For the automobile this lack of symmetry was not observed. The Goodrich study was performed in the U.S.A. where riders are required to ride on the right-hand side of the road, opposite to that in Australia. The reason for the asymmetry is not apparent; perhaps left or right-handedness is a key. Unfortunately, handedness data were not available for the test subjects.

On the skill test the rider's performance for exercise 8 is based on one attempt at the correct speed. If the performance asymmetry observed by Goodrich and in the present work is a general characteristic, it would appear that riders who are given a left-hand avoidance manoeuvre would be at an advantage in the test, since they would be more likely to succeed. Failing on this particular manoeuvre attracts a penalty of 5 points. According to the "Motorcycle Operator Skill Test Examiner's Manual" (NPSRI, 1976): "If more than 10 penalty points are assessed, an applicant should not be passed". The increased possibility of a 5-point penalty if a right-hand manoeuvre is administered would thus represent a fairly important bias in the test.

4.6.5 Straight and Curved Path Braking

The two emergency braking manoeuvres were next analysed to compare braking performance in straight and curved paths. Table 4.5 presents the mean, standard deviation and 90% confidence interval for stopping distance and speed for exercises 7 and 9. The "Standard distance" for each task is also shown. These results are also shown plotted in Figure 4.5.

It can be seen that, for the straight path (exercise 7), the riders were able, on average, to attain the 'standard' stopping distance. This was not the case for exercise 9 where the mean stopping distance was some 2 metres beyond the required standard distance.

A possible explanation for the discrepancy between the two exercises is as follows: The rear brake on the 400cc motorcycle used was particularly 'sensitive' and allowed most riders to lock the rear wheel. Comments passed by riders after riding the motorcycle indicated that this often occurred. Locking the rear wheel whilst braking in a curve causes the rear of the motorcycle to move laterally, and hence causes the motorcycle to deviate from the intended path. This condition was tackled by riders in two ways: In the first, riders would 'hang-in there'; in the second, they would ease off on the rear brake, allowing them to regain control, and then re-apply the brake. The first strategy generally resulted in a path error, the second a stopping distance error. The latter, being less hazardous, was preferred by most riders, leading to the longer stopping distances indicated in Figure 4.5. Locking the rear wheel while braking in a straight line, on the other hand, would have a minimal effect on the lateral motion and could be tolerated. This raises an important point regarding the use of an unfamiliar motorcycle to perform the test. Had riders been allowed to use their own motorcycle the results obtained may well have been different.

TABLE 4.5

PERFORMANCE STATISTICS FOR THE QUICK STOP EXERCISES

Exercise	Mean	Standard deviation	90% confidence interval for the mean
7. Quick Stop: Straight			
Distance (m)	12.9	3.1	12.2,13.6
Speed (km/h)	36.5	4.0	35.6,37.4
Standard distance* (m)	13.4		
9. Quick Stop: Curve			
Distance (m)	9.1	2.3	8.6,9.6
Speed (km/h)	24.0	2.7	23.4,24.6
Standard distance* (m)	7.3		

* Standard Distance is the stopping distance which a rider just sufficiently experienced to be considered 'qualified' for on-street operation would be expected to achieve in approximately 95% of attempts. These distances were established by the developers of the MOST from tests with three qualified riders. Data collected from braking-distance speed trials, were used to establish regression equations for each rider. The stopping distance standard became a regression line that was two standard deviations beyond the regression line established from the data of the three riders (McPherson and McKnight, 1976, pp 43).

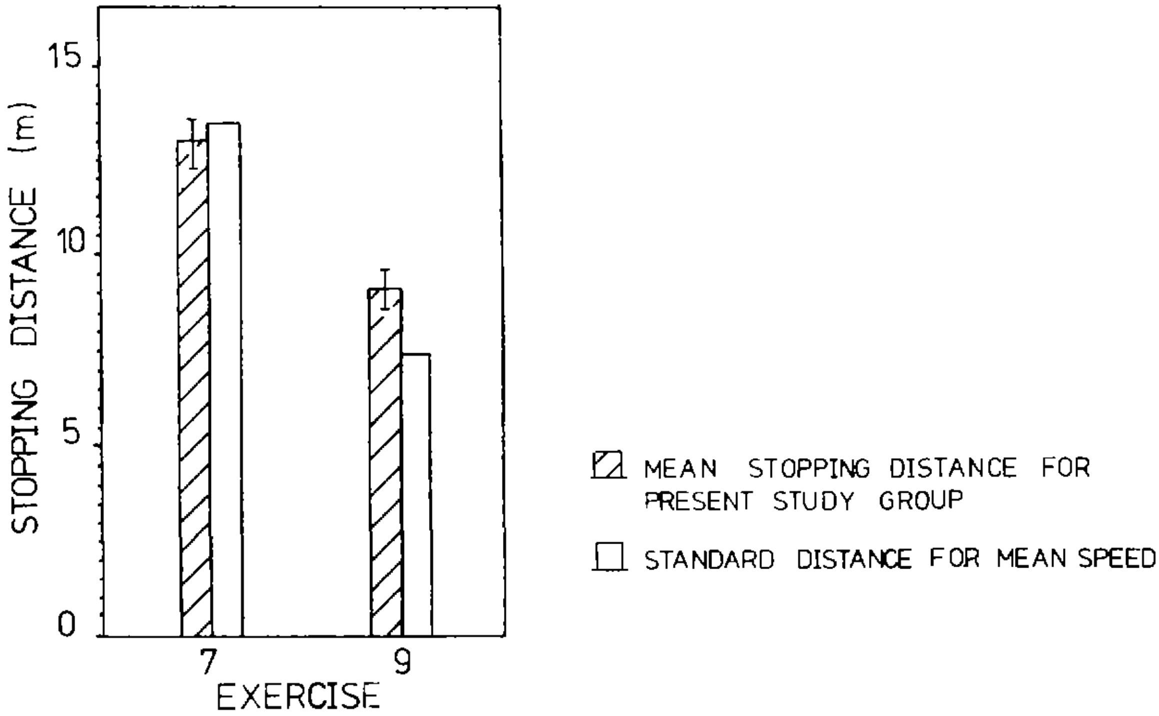

Figure 4.5 Comparison of actual stopping distance to standard distance for emergency braking exercises: straight path (7) and curved path (9).

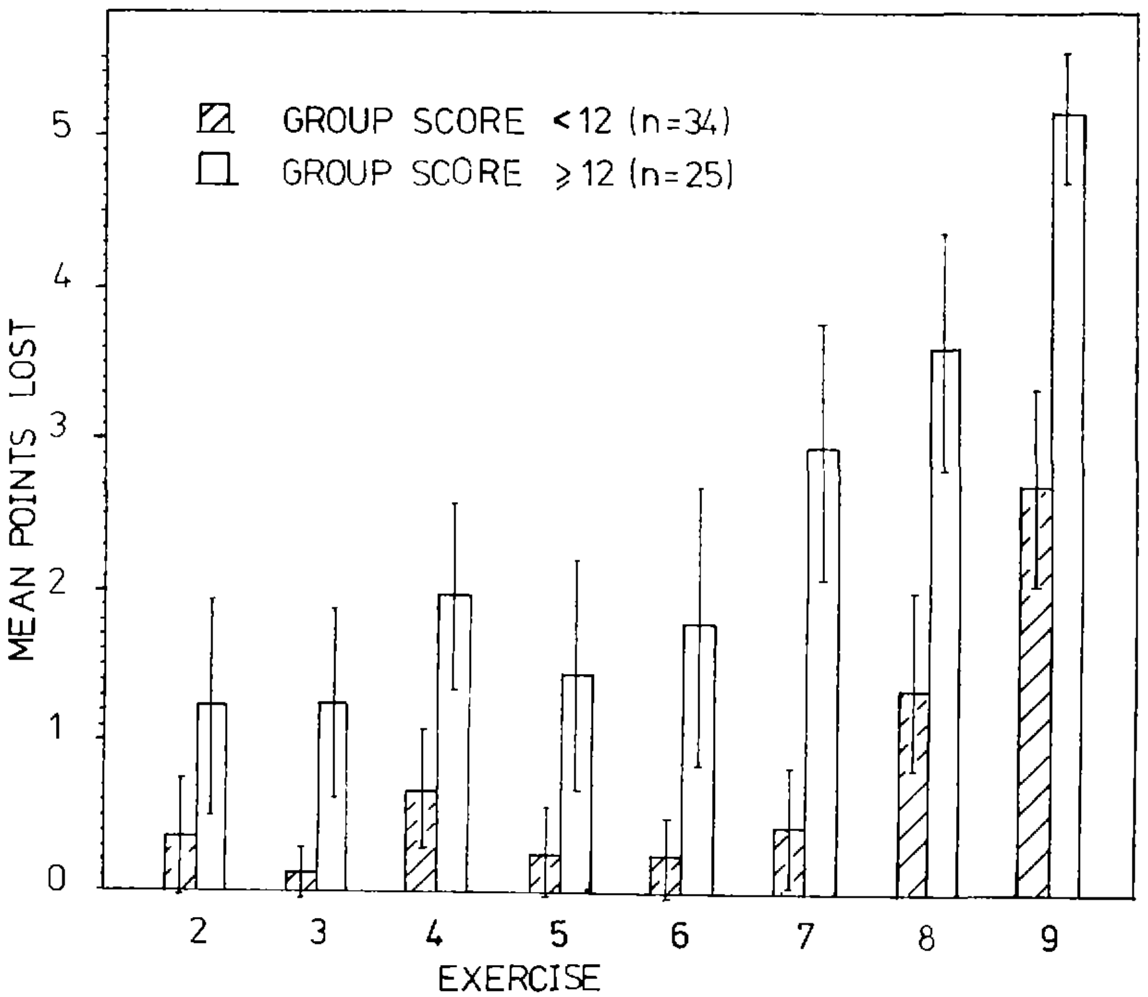

Figure 4.6 Results shown in table 4.6 plotted.

4.6.6 Skilled versus Less-Skilled Riders

In order to determine which manoeuvres discriminate best between the low scoring riders (who according to the test are more skilled) and the high scoring riders, the sample of riders was divided into two groups: Riders assigned less than 12 points formed Group A, those with 12 points or more formed Group B. Twelve was chosen as the criterion since the mean score for the whole sample was 11.70. Table 4.6 presents the means, standard deviations and 90% confidence intervals for scores assigned to each exercise for the two groups. The values represented in Table 4.6 are shown plotted in Figure 4.6. Performing a statistical test for each exercise (1-tailed t-test, since the test is to see whether the mean score for the less skilled group is the greater) indicates that, at the 0.05 level of significance, the Group A scores are lower for all the exercises. That is, the Group A riders performed consistently better over the entire test.

TABLE 4.6

STATISTICS OF EXERCISE SCORES FOR TWO SKILL GROUPS

	Group A Score < 12 (n=34)			Group B Score > 12 (n=25)		
Exercise	Mean	S.D.	90% C.I.	Mean	S.D.	90% C.I.
2	0.35	1.32	-0.03,0.73	1.21	2.08	0.50,1.92
3	0.12	0.54	-0.04,0.73	1.24	1.83	0.61,1.87
4	0.68	1.30	0.30,1.06	1.96	1.79	1.35,2.57
5	0.24	0.99	-0.05,0.53	1.44	2.20	0.69,2.19
6	0.24	0.89	-0.02,0.50	1.76	2.67	0.84,2.68
7	0.44	1.35	0.05,0.83	2.92	2.47	2.07,3.77
8	1.32	2.24	0.67,1.97	3.60	2.29	2.81,4.39
9	2.68	2.25	2.03,3.33	5.12	1.24	4.69,5.55
Overall	6.06	3.25	5.12,7.00	19.20	5.67	17.26,21.14

Table 4.7 and Figure 4.7 present a breakdown, by scoring criterion, of the scores shown in Table 4.6. The mean scores were again analysed to determine which aspects of the exercises were different for the two groups. At the 0.05 level of significance the following differences were observed: Group B path errors were higher for exercises 2, 3 and 4; time errors for exercise 3 and 6. Group B were more likely to skid on exercise 5 and their stopping distance errors were higher in the emergency braking exercises 7 and 9. Failure on the obstacle turn, exercise 8, was more common for Group B. Thus, virtually all the scoring criteria were consistent in discriminating between the low and high-scoring groups.

4.6.7 Score Distributions and Exercise Correlations

One way of determining the usefulness as a skill discriminator of each exercise on the skill test is to examine the histograms of score frequency shown in Figure 4.8. Exercises which have a uniform score distribution are useful in this sense, as they tend to increase the range of the overall scores obtained from a group of riders with a wide range of skill. Note that the increment for points lost on the abscissa of the diagrams is not the same for all exercises - because of the scoring system it is not possible to assign two penalty points for most of the exercises

The distributions for exercises 2, 3, 4, 5 and 6 are skewed to the lower points-lost region. These exercises are poor contributors to overall score and their main value would appear to be for a preliminary 'screening' of unskilled riders. Exercise 7 shows an extreme bi-modal score distribution, indicating a rather coarse discriminating power and suggests that a wider range of stopping distances for which penalty points are assigned should be considered. The scoring system for exercise 8 does not allow it to be any more sensitive a discriminator of skill: the result is either 'pass' or 'fail'. Exercise 9 shows a wide distribution of scores, with a concentration at 5 penalty points.

TABLE 4.7

BREAKDOWN OF SCORES FOR GROUPS A AND B

Exercise	Group A Score < 12 (n=34)			Group B Score >= 12 (n=25)		
	Mean	S.D.	90% C.I.	Mean	S.D.	90% C.I.
2. Sharp Turn						
a. Path	0.29	1.19	-0.06,0.64	1.17	2.10	0.45, 1.89
b. Feet	0.06	0.24	-0.01,0.13	0.04	0.20	-0.03, 0.11
3. Accelerative Turn						
a. Path	0.09	0.51	-0.06,0.24	0.68	1.44	0.19, 1.17
b. Time	0.03	0.17	-0.02,0.08	0.56	1.26	0.13, 0.99
4. Decelerative Turn						
a. Path	0.62	1.23	0.26,0.98	1.60	1.78	0.99, 2.21
b. Time	0.06	0.24	-0.01,0.13	0.32	0.85	0.03, 0.61
5. Stopping Judgement						
a. Skid	0.09	0.51	-0.06,0.24	0.84	1.37	0.37, 1.31
b. Stop	0.15	0.86	-0.10,0.40	0.60	1.66	0.33, 1.17
6. Turning Speed Judgement						
a. Path	0.15	0.86	-0.10,0.40	0.40	1.38	-0.07, 0.87
b. Time	0.09	0.29	0.01,0.17	1.36	1.96	0.69, 2.03
7. Quick Stop: Straight						
Distance	0.44	1.35	0.05,0.83	2.92	2.47	2.07, 3.77
8. Obstacle Turn						
Course	1.32	2.24	0.67,1.97	3.60	2.29	2.81, 4.39
9. Quick Stop: Curve						
a. Path	0.35	0.98	0.07,0.63	0.48	1.12	0.10, 0.86
b. Distance	2.32	2.29	1.66,2.98	4.64	1.08	4.27, 5.01
Total penalty points	6.06	3.25	5.21,7.00	19.2	5.67	17.76,21.14

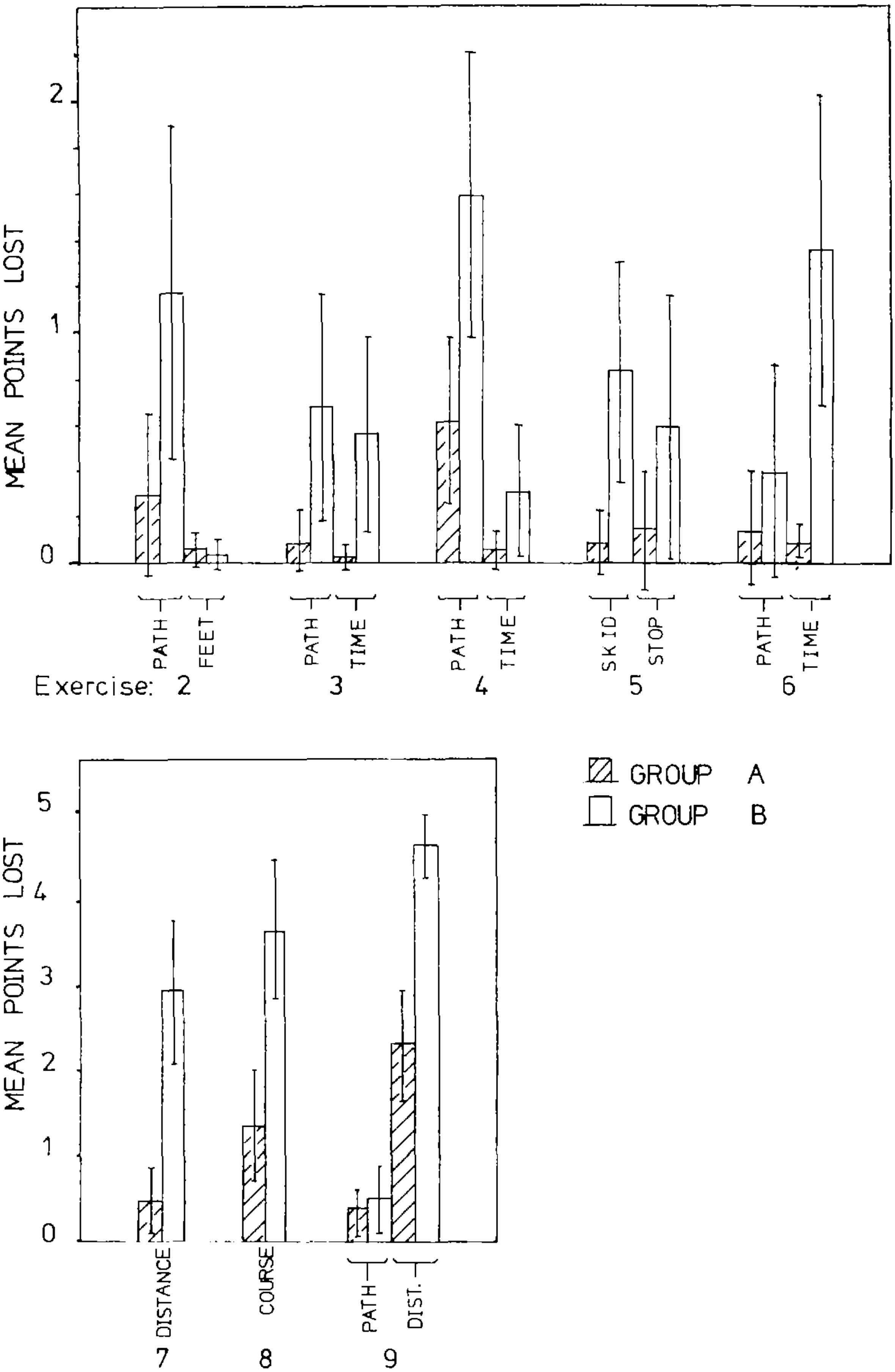

Figure 4.7 Results shown in table 4.7 plotted.

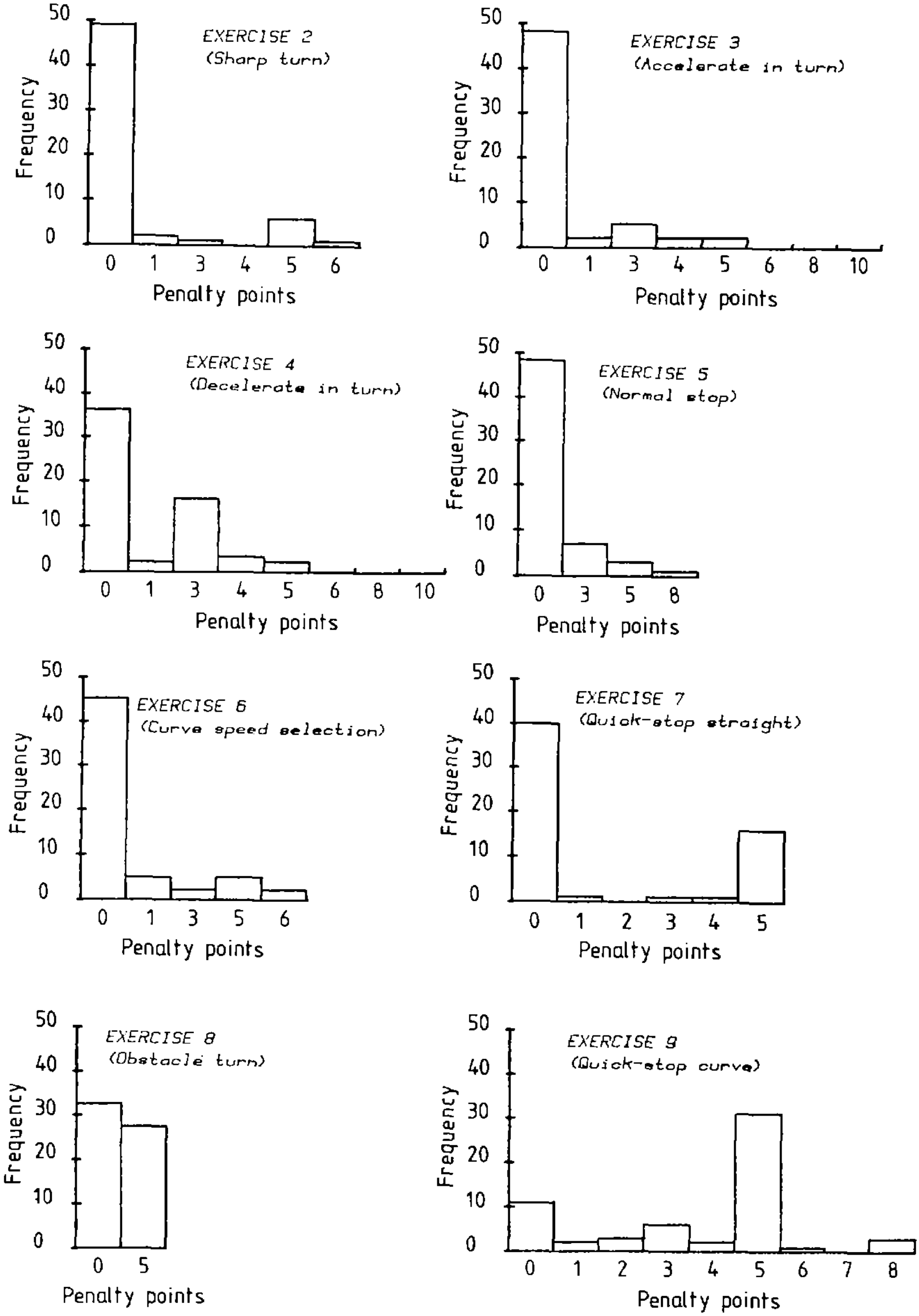

Figure 4.8 Histograms of score frequency.

It is important to examine the relationship between the exercise scores assigned to each rider and his/her overall test score to ensure that the contribution of each exercise score to overall score is in the same direction. For example, if for two exercises A and B, say, a skilled rider was assigned a score of 4 and 1 respectively, and for the same exercises an unskilled rider was assigned 1 and 4, the overall score for the two riders would be the same. One exercise would cancel the effect of the other. This information cannot be gleaned from the distributions discussed earlier. An estimate of the linear relationship between the score assigned to each rider for each exercise, and the rider's overall test score, can be obtained by calculating the correlation coefficient between these variables for each exercise. The correlation coefficients between the various exercises, and each exercise and overall score are listed in Table 4.8.

TABLE 4.8

CORRELATION MATRIX FOR OVERALL MOST SCORE AND THE INDIVIDUAL EXERCISE SCORES

	Overall MOST score	Exercise 2	3	4	5	6	7	8
Exercise								
2	0.299							
3	0.571	0.124						
4	0.326	-0.006	-0.006					
5	0.381	-0.163	0.095	0.174				
6	0.583	0.172	0.400	0.124	-0.055			
7	0.702	0.040	0.240	0.101	0.217	0.393		
8	0.540	0.005	0.376	0.022	0.058	0.159	0.300	
9	0.586	0.148	0.221	0.055	0.283	0.166	0.364	0.043

The exercise showing the highest correlation with the overall MOST score are:

7, Emergency braking-straight
9, Emergency braking-curve
6, Curve speed selection
3, Accelerating in a turn
8, Obstacle avoidance

The scores for the following exercises are only moderately correlated with each other:

exercise 3 with exercises 6 and 8
exercise 6 with exercise 7
exercise 7 with exercise 9

The remaining exercise score comparisons show very little correlation.

In summary, the first five exercises appear to be too easy to provide useful measures of skill, except perhaps at the lower skill levels. The straight-line emergency braking and the obstacle avoidance exercises (7 and 8) generally yielded extremes of penalty points, with little sensitivity in discriminating intermediate levels of skill. Exercise 9, emergency braking in a curve, proved to be the most difficult task. However, the difficulty could be strongly related to the control gains (or 'feel' characteristics) of the test motorcycle brakes.

4.7 COMPARISON WITH PREVIOUS WORK

4.7.1 Introduction

The analysis in section 4.6.6 indicated that the scoring criteria for virtually all the exercises were consistent in differentiating between the low and high scoring groups. In this section a comparison is made between the performance of the present study group of riders in the MOST, and two other groups of riders who were administered the same test. The first group of riders consisted of 168 learner riders while the second comprised 245 actual licence applicants. It is useful to make these comparisons as they indicate how the present group of riders differ from the learners and licence applicants. Further, the effect of differences in test administration, and their influence on the results of the test exercises which discriminate between the skilled and less-skilled groups, can be examined.

4.7.2 Comparison with Pilot Study

The first comparison was made with the 'pilot study' performed by McPherson and McKnight (1976), in which 168 subjects were tested. Details pertaining to test administration in their pilot study are as follows:

- Applicants were informed as to the nature of the test, including the exercises to be performed and the scoring criteria.

- Applicants had the choice of riding their own motorcycle or 200cc ones supplied. Most applicants elected to ride the motorcycles provided. These persons were acquainted with the test motorcycle and allowed to operate it for approximately 5 minutes prior to test administration.

The sample of riders selected were required to meet the following criteria:

1. A beginning on-street motorcycle rider.
2. Unlicenced or licenced for less than 6 months.
3. At least 16 years old.

It was found that the applicants were not as well motivated as actual licence applicants.

Compared to these riders, it was mandatory that subjects in the present study ride the 400cc (instrumented) motorcycle which was supplied. There was no restriction on riding experience; i.e., riders ranged from being rank novice to highly experienced. As in the McPherson and McKnight pilot study, the present riders may not have been as strongly motivated as actual licence applicants.

Table 4.9 compares the means, standard deviations and 90% confidence intervals of exercise scores for the present study group and the pilot study group. As mentioned earlier, these scores represent penalty points assigned due to errors. Therefore, the higher the score the poorer the performance on the test. The results are also plotted in Figure 4.9.

The general trend of the exercise means for the two groups is very similar. The present study group has a lower mean score for six of the exercises. This is to be expected, since the range of riding experience for the present study group is much wider and consequently the average level of riding skill should have been higher.

One-sided t-tests were performed to determine whether the means for the pilot study group were larger than the means for the present study group for each exercise. The present study group had lower means for exercises 3, 6, 7 and 8 at $p<0.01$. The mean for exercise 2 was lower at $p<0.05$. Therefore the exercises which appear to discriminate highly between the two groups are:

3, Accelerating in a right-turn
6, Curve speed selection, left-hand curve
7, Quick stop-straight
8, Obstacle turn

Recall from section 4.6.7 that these exercises (together with exercise 9) had the highest correlation with overall score.

TABLE 4.9

COMPARISON BETWEEN PRESENT STUDY AND McPHERSON AND McKNIGHT (1976) PILOT STUDY

Exercise	Present study (n=59)			Pilot study (n=168)		
	Mean	S.D.	90% C.I.	Mean	S.D.	90% C.I.
2	0.69	1.70	0.32,1.06	1.27	2.24	0.98,1.50
3	0.59	1.37	0.29,0.89	1.12	1.70	0.90,1.34
4	1.22	1.64	0.86,1.58	1.53	1.95	1.28,1.78
5	0.74	1.71	0.37,1.11	0.51	1.10	0.37,0.65
6	0.88	1.99	0.45,1.31			
6*	0.59	1.63	0.24,0.94	1.47	2.29	1.15,1.79
7	1.49	2.25	1.00,1.98	2.37	2.30	2.08,2.66
8	2.28	2.51	1.74,2.84	3.40	2.70	3.05,3.75
9	3.78	2.20	3.30,4.26	3.54	3.10	3.14,3.94
Overall	11.70	7.89	9.98,13.42	15.21	-	- -

* Scoring criteria for this exercise in the pilot study were based on a 2.6 second timing standard. A 2.4 second standard was later adopted and also used in the present study. The values in this line represent the score which would have been obtained in the present study had a 2.6 second standard been used.

It is interesting to note that, whereas the present study group's performance was superior in the straight-line braking exercise (7), there was no statistical difference between the two groups for the braking in a turn exercise (exercise 9), and the stopping judgement exercise (exercise 5). For the stopping judgement exercise, in which penalty points are assigned for a wheel skid, more than half of the mean points assigned were due to a rear wheel skid. This again suggests that the sensitive rear brake on the present 400cc motorcycle

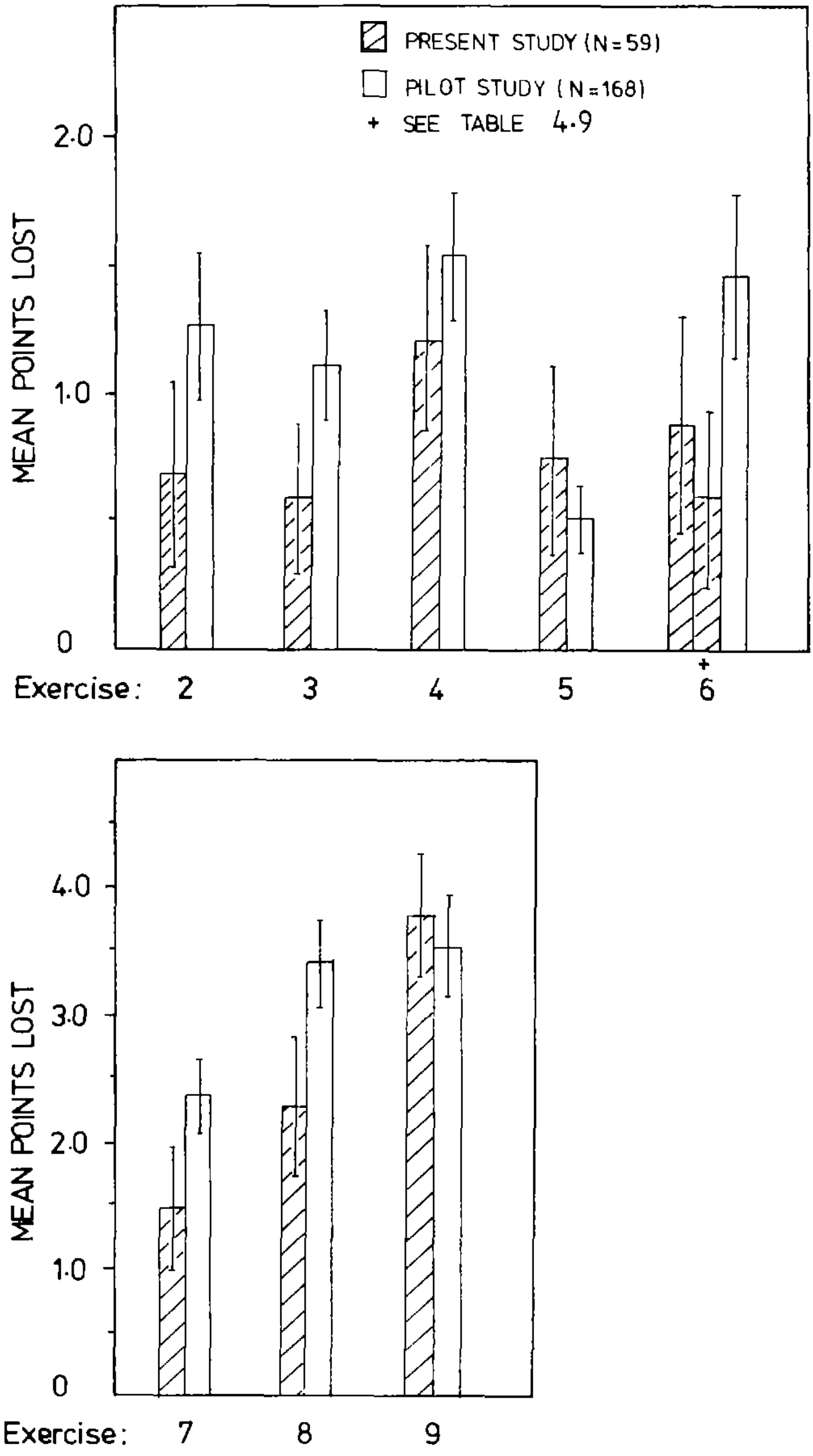

Figure 4.9 Means and 90% confidence intervals of exercise scores for the present study group and the McPherson and McKnight (1976) pilot study group.

made the curved-path braking exercise and stopping judgement exercise rather difficult. In the straight-line quick stop, however, locking of the rear brake would be less serious for path stability, and the present group presumably made better use of the front brake than did McPherson and McKnight's subjects.

4.7.3 Comparison with Operational Test Group

The 'operational test' performed by McPherson and McKnight (1976), was administered as part of a much larger project (see Anderson, 1978). The 245 subjects tested were actual licence applicants. One would expect the operational test group to be more motivated than the present study group or McPherson and McKnight's (1976) pilot study group, and that this motivation might be reflected in performance on the test.

Administration of the operational test differed from that for the pilot study. Information given to the pilot study group verbally was presented to the operational test group in a manual. It was found after a test-retest analysis that the more important information had to be incorporated as an additional instruction sheet (see first page of Appendix C) so as to increase the applicants' awareness of these particular aspects of the test. No mention is made in the report as to when this modification was incorporated in the operational test. The test-retest differences were found to be largest for exercises 6 through 9, the more difficult exercises.

Table 4.10 compares the means for the present study group and the operational test group. Mean score data only are presented in the McPherson and McKnight report for the operational test and hence confidence intervals for the means are not shown. The results are also shown plotted in Figure 4.10.

The general trend in the means for the two comparison groups is again very similar. The present study group mean is lower for 5 of the exercises.

Table 4.11 shows a comparison of the mean points lost for the various scoring criteria on each exercise for the operational test group. Such a breakdown of the data is not presented for the pilot study group in the McPherson and McKnight report. It can be seen that for exercise 2 the present, more experienced group lost less points for use of feet for balance, implying a more precisely co-ordinated performance. Path deviations are identical for exercises 2 and 3 and time is the apparent discriminator for exercise 3. Once again, the present study group's performance was inferior in the curved-path braking exercises 4 and 9, with particularly poor path-keeping in exercise 4.

TABLE 4.10

COMPARISON OF EXERCISE MEAN SCORE FOR PRESENT STUDY GROUP AND McPHERSON AND McKNIGHT'S OPERATIONAL TEST GROUP

Exercise	Mean score	
	Present study (n=59)	Operational test (n=245)
2	0.69	0.89
3	0.59	0.97
4	1.22	0.79
5	0.74	0.47
6	0.88	1.33
7	1.49	2.36 (2.72)*
8	2.29	2.30 (2.89)*
9	3.78	2.30 (3.65)*
Total	11.70	11.41 (13.71)*

* During the operational test, applicants losing 16 or more points were not allowed to continue the test (i.e. they failed). The number in parenthesis therefore represents points deducted had the applicants continued on the test and failed on all remaining exercises.

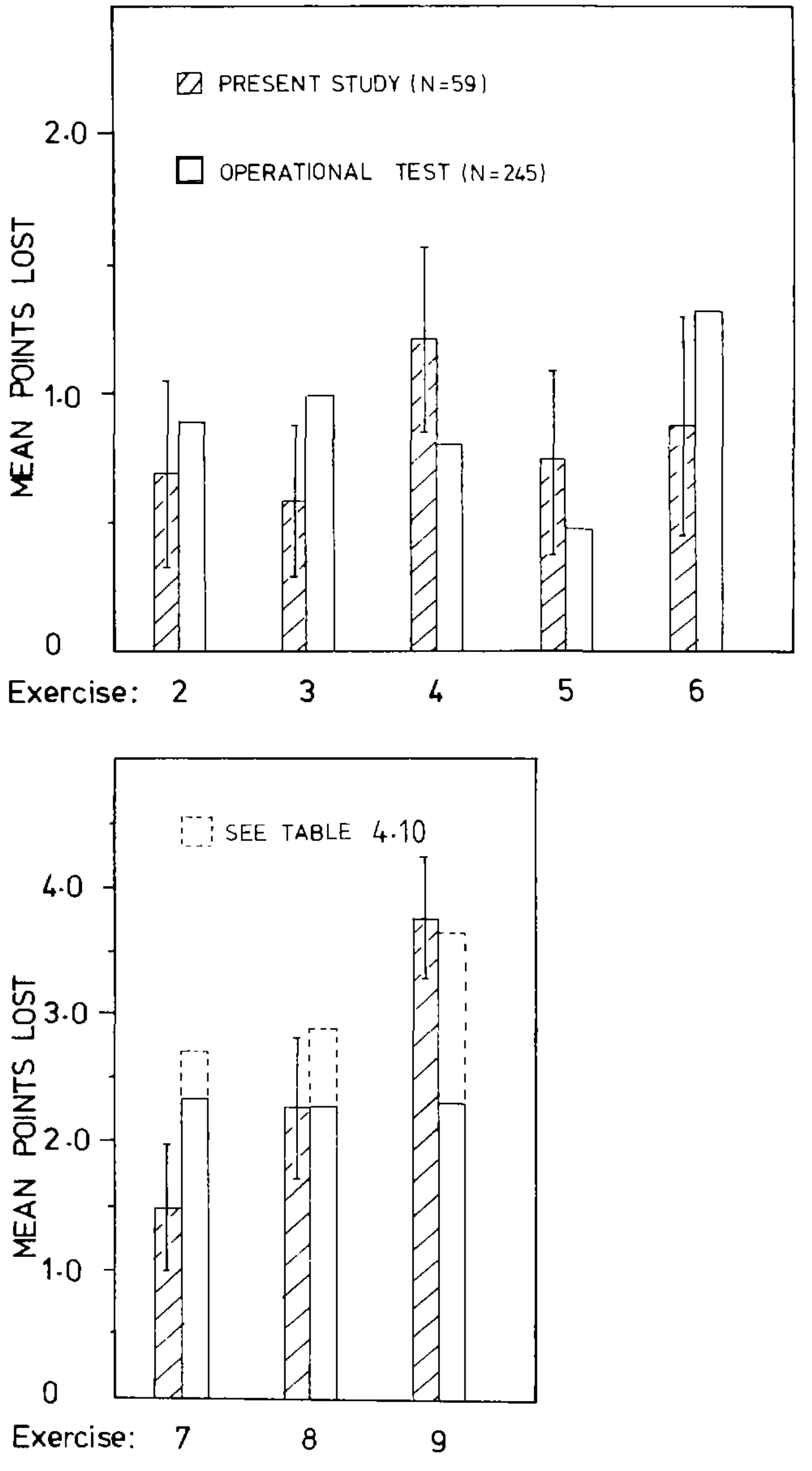

Figure 4.10 Comparison of means and 90% confidence intervals for the present study group with means for the McPherson and McKnight (1976) operational test group for each exercise.

TABLE 4.11

COMPARISON OF COMPONENTS OF MEAN EXERCISE SCORES BETWEEN PRESENT STUDY GROUP AND McPHERSON AND McKNIGHT'S OPERATIONAL TEST GROUP

Item and performance criteria	Present study group (n=59)	Operational test (n=245)
2. Sharp Turn		
a. Path	0.64	0.65
b. Feet	0.05	0.24
3. Accelerative Turn		
a. Path	0.34	0.36
b. Time	0.25	0.61
4. Decelerative Turn		
a. Path	1.03	0.19
b. Time	0.17	0.60
5. Stopping Judgement		
a. Skid	0.41	0.30
b. Stop	0.34	0.17
6. Turning Speed Judgement		
a. Path	0.25	0.67
b. Time	0.63	0.65
7. Quick Stop: Straight		
Distance	1.49	2.36 (2.81)*
8. Obstacle Turn		
Course	2.29	2.30 (2.89)*
9. Quick Stop: Curve		
a. Path	0.41	0.25
b. Distance	3.36	2.30 (3.69)*
Total points deducted	11.70	11.41 (13.71)*

* refer to Table 4.10

The reason for the difference in path deviations for exercise 4 is not readily apparent. It could be related to the rear brake sensitivity, or it is possible that the motorcycle used has a poor handling characteristic, during deceleration, over the test speed range which did not show up in the handling tests described in Chapter 3. It should be noted that licence applicants in the operational test had a choice of riding their own motorcycle or 200 cc ones provided.

The present study group had the higher scores in exercise 5 for both the rear wheel locking and stopped position criteria. This was explained earlier in terms of the rear brake sensitivity of the present test motorcycle.

Exercise 6 shows trends similar to exercises 2 and 3, the discriminator in this manoeuvre being path deviation. This manoeuvre is performed in the same direction (to the left) as exercise 4, but at a relatively constant speed and on a wider path. This further emphasizes the particular difficulty the present group had in curved-path braking.

Clearly for exercise 7 the present study group's performance is superior, as expected, and exercise 8 shows this trend also, but not as strongly. The poor performance for exercise 9 could partially be attributable, as for exercise 4 and 5, to the rear brake sensitivity of the motorcycle used.

In summary, the comparisons made between the present study and McPherson and McKnight's pilot and operational tests show similar trends. The present group was more experienced than the licence applicants in McPherson and McKnight's groups and, on the whole, their performance was better. However, the present group found the slowing and braking in a turn manoeuvres and stopping judgement exercise relatively more difficult, possibly due to the use of an unfamiliar motorcycle with a sensitive rear brake.

4.8 PREDICTORS OF MOST SCORES

4.8.1 Introduction

Rider background factors obtained via a questionnaire were used in conjunction with the MOST score assigned to each rider in a multiple linear regression analysis, to determine which factor(s) are the 'best' predictors of score. The questionnaire given to riders was arranged in two sections. Part A was given to all subjects prior to taking any test. It was primarily concerned with obtaining general information such as age, riding experience etc. (see Appendix B). Part B of the questionnnaire was only given to subjects who participated in the second experiment (Chapter 5) after they had completed the test. This was done so that the subjects would not be influenced by the questions posed, as they tested the rider's knowledge of motorcycle handling skills (also in Appendix B). Results pertaining to part B of the questionnaire are in Chapter 6.

4.8.2 Means, Standard Deviation and Correlation Coefficients

Table 4.12 shows the mean, standard deviation and number of cases for the dependent variable SCORE and the independent variables used in the analysis. In addition, the mnemonics used for the independent variables are defined. To have included other factors asked for in the questionnaire would have reduced the number of cases considerably. For example, kilometres ridden per week off-road was excluded since many riders could not estimate their weekly off-road travel. Inclusion of this variable would have reduced the number of cases by 24. A run was however performed to determine whether this variable was significant as a predictor of score for the 30 cases available. It was not found to be significant as a predictor.

As noted earlier, large capacity motorcycles are somewhat over-represented in the present study group. In addition 85% of the sample are males. Being largely composed of males is not inconsistent with other studies. For example, the Pilot Study of McPherson and McKnight

TABLE 4.12

STATISTICS FOR VARIABLES USED IN THE ANALYSIS
OF BACKGROUND FACTORS

Variable	Mean	Standard deviation
SCORE	11.70	7.89
SEX[1]	0.70	0.71
AGE[2]	26.28	6.77
EONRD[2]	4.45	5.06
EOFFRD[2]	2.24	4.59
KMWK	219.02	150.85
ENGCAP[3]	525.74	264.78
DL[4]	0.67	0.75
LP[4]	-0.85	0.53
COMPEX[4]	-0.59	0.81

Notes: Number of cases = 54

[1] Male = 1, Female = -1
[2] Years
[3] Cubic centimetres
[4] Yes = 1, No = -1

EONRD	Riding experience on road (in years)
EOFFRD	Riding experience off road (in years)
KMWK	Kilometres ridden/week on-road
ENGCAP	Engine capacity of motorcycle most often ridden
DL	Drivers licence
LP	Learners permit
COMPEX	Competition experience

(1976) was 90% male. A study performed in Canada by Jonah and Dawson (1979), to be discussed shortly, had a sample of 637, 92% of whom were males. The large proportion of males appears to be representative of the general riding population. Relatively speaking, therefore, the present study sample has a fairly large proportion of females.

Demographic and experiential factors for each applicant in the Pilot Study group in the McPherson and McKnight (1976) study were obtained via a questionnaire. An attempt to determine the relation between test performance and background factors was complicated by many of the subjects having little or no riding experience. Subjects who were not currently riding a motorcycle were not included in the determination and total miles ridden per week was used as the index of experience for the remaining sample. A correlation of 0.41 was found between score on the skill test and total miles ridden per week. This is the only result cited in the report relating test results to background factors.

Table 4.13 shows correlation coefficients calculated from information given by the test subjects used in this study. The correlation coefficient for score and total number of kilometres ridden per week is -0.47, the negative sign indicating that the more you ride, the better your performance on the skill test. This compares well with McPherson and McKnight's result. Other variables which are 'highly' correlated with score are sex (SEX,-0.48), off-road experience in terms of years ridden (EOFFRD,-0.28), engine capacity of motorcycle most often ridden (ENGCAP,-0.39) and competition experience (COMPEX,-0.33).

The independent variables which correlate highly with each other are SEX and ENGCAP, indicating that the males in this sample generally rider larger capacity motorcycles, EONRD with AGE, EOFFRD and ENGCAP with EONRD, ENGCAP and COMPEX with EOFFRD, COMPEX with ENGCAP, and LP with DL.

TABLE 4.13

CORRELATION COEFFICIENTS FOR VARIABLES USED IN THE REGRESSION ANALYSIS

	SCORE	SEX	AGE	EONRD	EOFFRD	KMWK	ENGCAP	DL	LP
SEX	-0.48								
AGE	0.19	0.05							
EONRD	-0.05	0.17	0.62						
EOFFRD	-0.28	0.20	0.02	0.32					
KMWK	-0.47	0.01	-0.23	-0.15	-0.02				
ENGCAP	-0.39	0.33	-0.01	0.32	0.41	0.17			
DL	0.16	-0.19	0.19	0.12	-0.06	-0.19	0.17		
LP	-0.07	0.12	-0.22	-0.19	-0.08	0.20	-0.25	-0.44	
COMPEX	-0.33	0.21	-0.04	0.20	0.65	0.05	0.42	-0.02	-0.14

Note: Number of cases = 54

4.8.3 Regression Analysis

Table 4.14 summarizes the results of a stepwise linear multiple regression analysis performed on data obtained in this study to determine which independent variables (e.g. age, sex, etc.) predict score (dependent variable) on the skill test. When the regression analysis is performed in a stepwise manner, the independent variables are entered into the regression equation only if they meet certain statistical criteria (Nie et al, 1975). The order of inclusion (which has been preserved in the table) is determined by the respective contribution of each variable to variance. Table 4.15 shows the regression coefficients and the associated 95% confidence intervals. For the regression, interaction terms were considered up to 3rd order and were found to be not statistically significant when their constituent elements were controlled for.

TABLE 4.14

SUMMARY OF MULTIPLE REGRESSION ON MOST SCORES

Independent variable	R	R^2	ΔR^2	Simple r	F to enter	Significance when entered into equat'n
SEX	0.482	0.233	0.233	-0.482	15.77	0.000
KMWK	0.696	0.448	0.215	-0.469	19.87	0.000
COMPEX	0.701	0.491	0.044	-0.328	4.28	0.044
AGE	0.708	0.502	0.011	0.193	1.08	0.304
ENGCAP	0.715	0.511	0.009	-0.389	0.89	0.352
EOFFRD	0.718	0.516	0.005	-0.277	0.45	0.507
EONRD	0.720	0.518	0.003	-0.050	0.24	0.623
LP	0.722	0.521	0.002	-0.071	0.21	0.646
DL	0.722	0.521	0.000	0.167	0.01	0.905

Note: Overall significance of regression is $p<0.0005$

52.1 percent of the variance in skill test score is explained by the independent variables (predictors) listed. The following, in order, accounted for more than 1% of the variance in score. Sex (23.3%), kilometres ridden/week (21.5%), competition experience (4.4%) and age (1.1%). The first two independent variables alone account for 86% of the explained variance in score and are the only variables which remain significant when the other variables are entered into the equation (controlled for). COMPEX was significant at the 5% level when it was first entered into the equation - however, controlling for the other variables rendered it not significant (see confidence interval for this variable in Table 4.15).

TABLE 4.15

REGRESSION COEFFICIENTS AND 95% CONFIDENCE INTERVALS

Variable	Regression coefficient	95% confidence interval
SEX	-4.6221	-7.2321,-2.0121
KMWK	-0.0226	-0.0347,-0.0106
COMPEX	-1.0487	-3.8477, 1.7504
AGE	0.1981	-0.1447, 0.5410
ENGCAP	-0.0018	-0.0103, 0.0067
EOFFRD	-0.1374	-0.6459, 0.3709
EONRD	-0.1204	-0.6037, 0.3629
LP	0.8773	-2.8704, 4.6250
DL	0.1545	-2.4424, 2.7514
CONSTANT	16.5032	6.4025, 26.604

The fact that sex was found to be the best predictor of score is not inconsistent with other research. A study performed in Canada by Jonah and Dawson (1979), aimed at determining what demographic and experiential factors are related to scores obtained with the MOST, found that age, sex and riding experience were the most important predictors of skill test score. These accounted for the greatest amount of the explained variance. Jonah and Dawson noted that the observation that males performed better than females is consistent with previous research on sex differences in car driving performance.

A stepwise regression analysis was also performed by Jonah and Dawson to determine which independent variables predicted score. The score was computed as follows:

$$\text{Total score} = \sum_{i=1}^{9} [(TP_i + 1) - PL_i]A_i$$

where: TP = total possible points that could be lost on exercise i

PL = actual points lost on exercise i

A = attempted exercise (1=yes, 0=no)

The resultant scores ranged from 1 to 80 with larger scores representing a higher level of skill. Subjects used were applicants for a motorcycle operators licence. Each applicant was administered the skill test followed by the regular provincial licensing test. The sample included only those individuals who passed the provincial licensing test, which represented about 80% of the total number of applicants tested. The potential bias present due to filtering the sample with the provincial test should be noted.

The second-best predictor of score found in the present study was kilometres ridden per week. This indicates, as one would intuitively expect, that constant practice improves the riding skills measured by the skill test.

The three variables SEX, KMWK and COMPEX, as shown in Table 4.14, were significant at the 5% level when they were first entered into the equation. Table 4.15 shows the estimates for the regression coefficients, with their associated confidence intervals. The regression coefficients indicate that when the other variables are controlled for, only SEX and KMWK remain significant. Therefore, being male and riding more kilometres per week lead to improved scores.

As mentioned earlier, age, sex and riding exerience (both quantity and quality) were the most important predictors of skill test score in the Jonah and Dawson study. The fact that young applicants were found to perform better than older applicants is consistent with the present study, although this effect was not statistically significant. According to Jonah and Dawson, the age variable may represent an agility factor which favours younger riders.

Another point of interest arising from the regression coefficients is that normally riding a large capacity motorcycle contributes positively to test performance. It will be recalled that subjects in this study were required to ride the 400cc motorcycle provided. Thus the size of the motorcycle which the subject normally rides should be measured relative to 400cc; i.e. anything larger than 400cc would be considered as large capacity. The results obtained show that subjects who normally ride a large capacity motorcycle, when given a smaller capacity machine to ride, handled it better than subjects who normally ride a small capacity machine and were given a larger capacity machine to ride.

This could be due to a self-selection process; i.e. riders owning large capacity motorcycles may feel they have acquired the skills necessary to manoeuvre and control larger capacity machines. On the other hand, the less skilled rider, feeling less competent, may be attracted to smaller machines. One might also expect subjects who ride large capacity machines to ride more, since the motorcycles are more suitable for travelling long distances. Thus their better performance could be a result of increased exposure (KMWK). Table 4.13, however, shows ENGCAP and KMWK to be only weakly correlated.

A stepwise regression analysis of subject characteristics was performed by Anderson (1978) to determine which characteristics predict success on the motorcycle skill tests used in three licensing programs being evaluated. The first was the current standard California licensing program; the second consisted of an improved manual, knowledge and skill test, and remedial training for persons who failed the skill test on their first attempt; the third was similar to the second, but without remedial training for skill test failures. The improved skill test used in the second and third programs was that developed by NPSRI (1976). Two criteria were used for the regression analysis: the first investigated first administration performance of the skill test; the second, performance over all administrations of the skill test. The following three variables predicted first administration performance in each licensing program - field office area, whether or not the subject had previously ridden a motorcycle, and sex. Males and subjects who had previously ridden a motorcycle were more likely to pass their first skill test than females and subjects who had not previously ridden a motorcycle. The result pertaining to sex found here is consistent with results obtained in the present study and that of Jonah and Dawson (1979). Only one variable, age, predicted performance over all administrations, older subjects being more likely to pass than younger subjects. This result is inconsistent with Jonah and Dawson and the present study, where younger riders were found to perform better.

In summary, the regression analysis showed the following two variables (background factors) to be the 'best' predictors of test score: rider sex, and how many kilometres are ridden in the average week. These results are largely consistent with other studies.

4.9 A LOOK AT THE MOST STOPPING DISTANCE CRITERION

4.9.1 Introduction

The data collected with the instrumented motorcycle provides the means by which to examine the performance standard set by McPherson and McKnight (1976) for the emergency straight-line braking exercise in the MOST. The standard was examined here by calculating the minimum average deceleration which riders had to achieve to satisfy the stopping distance criterion for the range of acceptable entry speeds. For this calculation it was necessary to obtain an estimate for average rider reaction time in this exercise.

4.9.2 Reaction Time for the Emergency Braking Exercise

A typical example showing how reaction time was extracted from the data traces for the straight-path emergency braking task (exercise 7), in the MOST, is shown in Figure 4.11. The resulting reaction time estimate for the 'total' sample is listed in Table 4.16.

4.9.3 The MOST Stopping Distance Criterion

Figure 4.12 shows the minimum deceleration requirements for the emergency braking (straight) exercise which riders must achieve to not attract any penalty points. The data in the figure is based on a 0.410s reaction time and the table of 'standard stopping distances' given in the MOST examiner's manual (NPSRI, 1976). Shown also are the

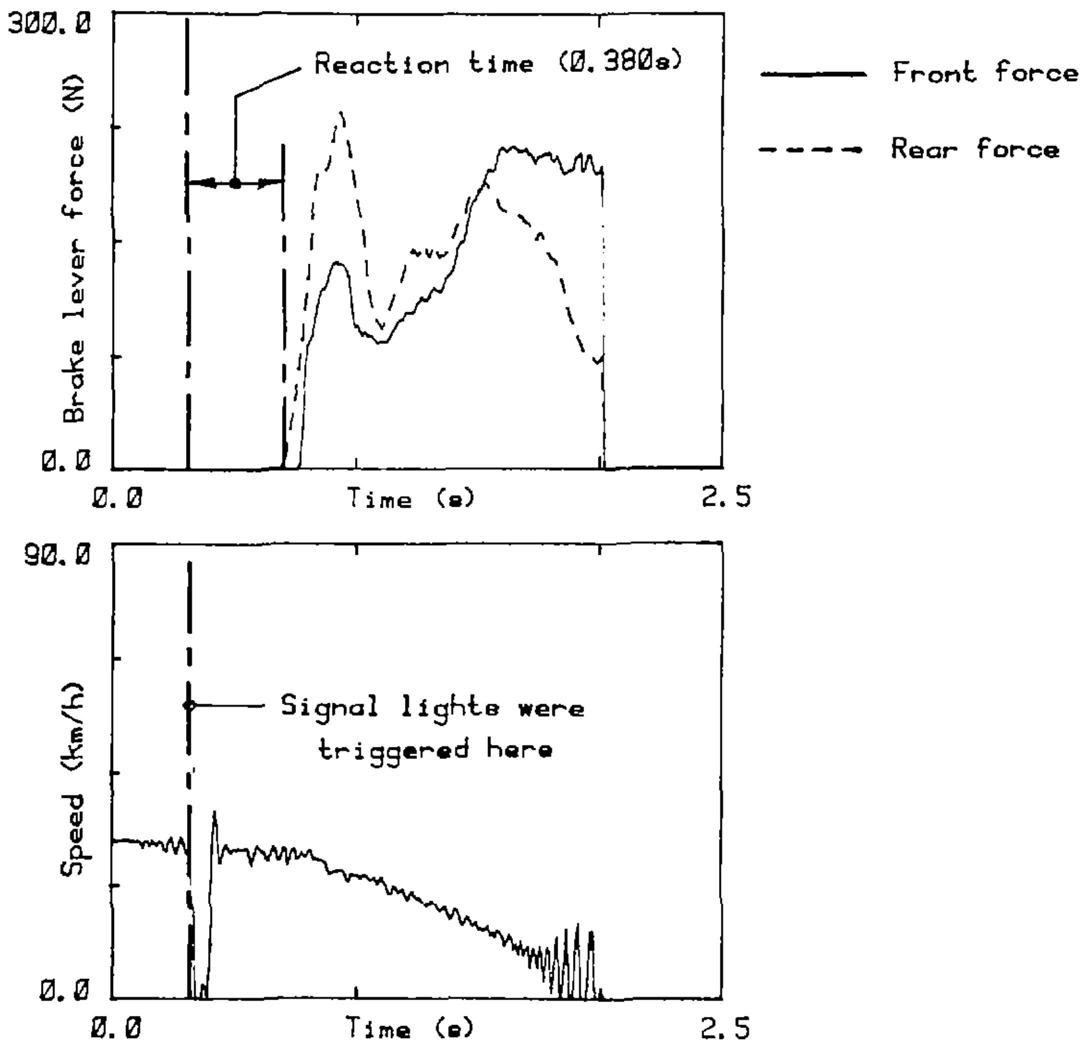

Figure 4.11 Reaction time from the data traces for the emergency braking.

minimum deceleration requirements based on reaction times which are two standard deviations either side of the mean, i.e., the range within which the reaction times for 95% of the sample lie. The calculation of minimum deceleration was based on the assumption that rider reaction time is not dependent on motorcycle speed. Note that a given standard stopping distance covers a small range of entry speeds, hence the peculiar form of the data in the figure.

The figure shows that the loci of mean deceleration have a minimum value for an entry speed of approximately 27.8 km/h. Riders travelling at 40 km/h, and who have a reaction time of 0.410 s, have to achieve approximately 35 percent more deceleration than riders travelling at 27.8 km/h. Therefore, riders travelling at too high or too low a speed, have to achieve a higher mean deceleration in order to satisfy the test performance criterion. This criterion would obviously favour riders travelling at the speed at which the minimum occurs. To examine the consequences of the speed dependent performance measure, the difference between the required stopping distances, as specified by the standard distance table, and the stopping distances based on a constant deceleration performance level was

TABLE 4.16

REACTION TIME ESTIMATE FOR EXERCISE 7 (QUICK-STOP STRAIGHT)

Exercise	Mean (s)	Standard deviation	Sample size	90% confidence interval for mean
7	0.410	0.082	52*	0.429,0.391

* The sample size is less than the total tested because some riders tried to anticipate the triggering of the signal lights and reacted before the lights came on; i.e., they 'cheated'. For other runs the data was too 'noisy'.

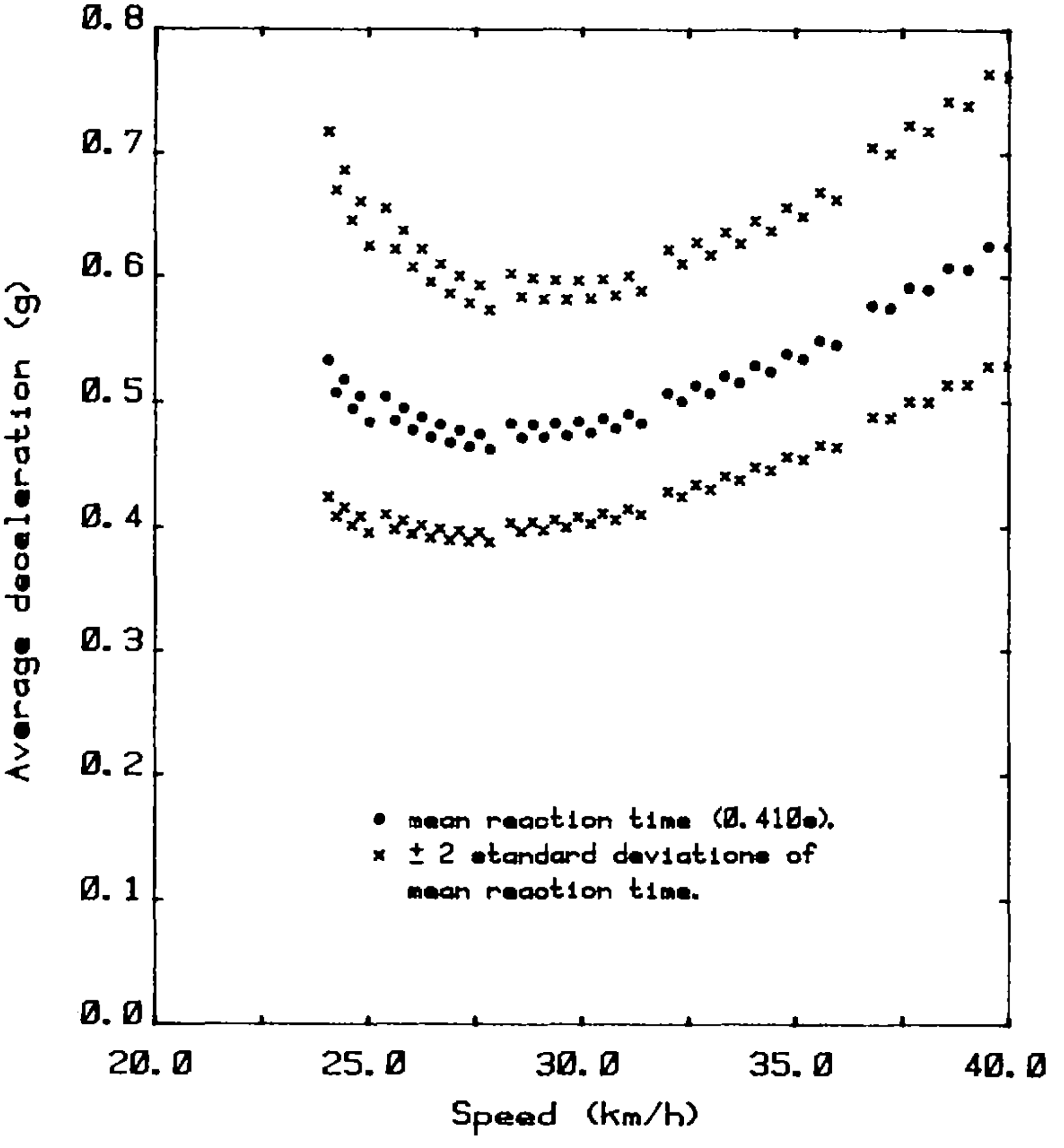

Figure 4.12 Calculated mean deceleration levels for the MOST stopping distance criterion.

determined. A criterion deceleration performance level of 0.5 g was established from the prescribed test manoeuvre speed of 32 km/h, the acceptable stopping distance for this speed of 11.6 m (38 ft), and the reaction time of 0.410 s. Using this level for the entire acceptable speed range, the stopping distances were calculated and are shown plotted in Figure 4.13 with the MOST standard stopping distances plotted for comparison. Shown also is the effect of varying the reaction time. The range of stopping distance values contain the MOST standard distances for speeds up to about 37 km/h. To check the effect of the difference between the two criteria, the overall test scores for the present study group of riders were recalculated using the criterion stopping distances based on the 0.5 g deceleration performance level and the mean reaction time of 0.410 s.

For the sample of 59 riders administered the MOST, 12 percent were affected by the difference in the standards. The overall test scores for all subjects were recalculated and it was found that the mean score dropped from 13.4 to 9.7; a reduction in mean score of 27.6 percent!

To avoid this significant bias in the test, it is suggested that modified stopping distance values be calculated using a 0.5g deceleration performance level for the entire acceptable speed range. Note that a similar bias exists for exercise 9 (Quick-Stop Curve) and it is suggested that a similar modification be made. To examine the MOST as it stands at present, the unmodified criteria for these two exercises were used throughout this report unless otherwise stated.

4.10 SUMMARY AND CONCLUSIONS

(i) An analysis of the scores obtained by the present study group shows the mean score for the following exercises on the MOST to be higher than at least one of the other exercises:

7, Emergency Braking: Straight

8, Obstacle Turn

9, Emergency Braking: curve

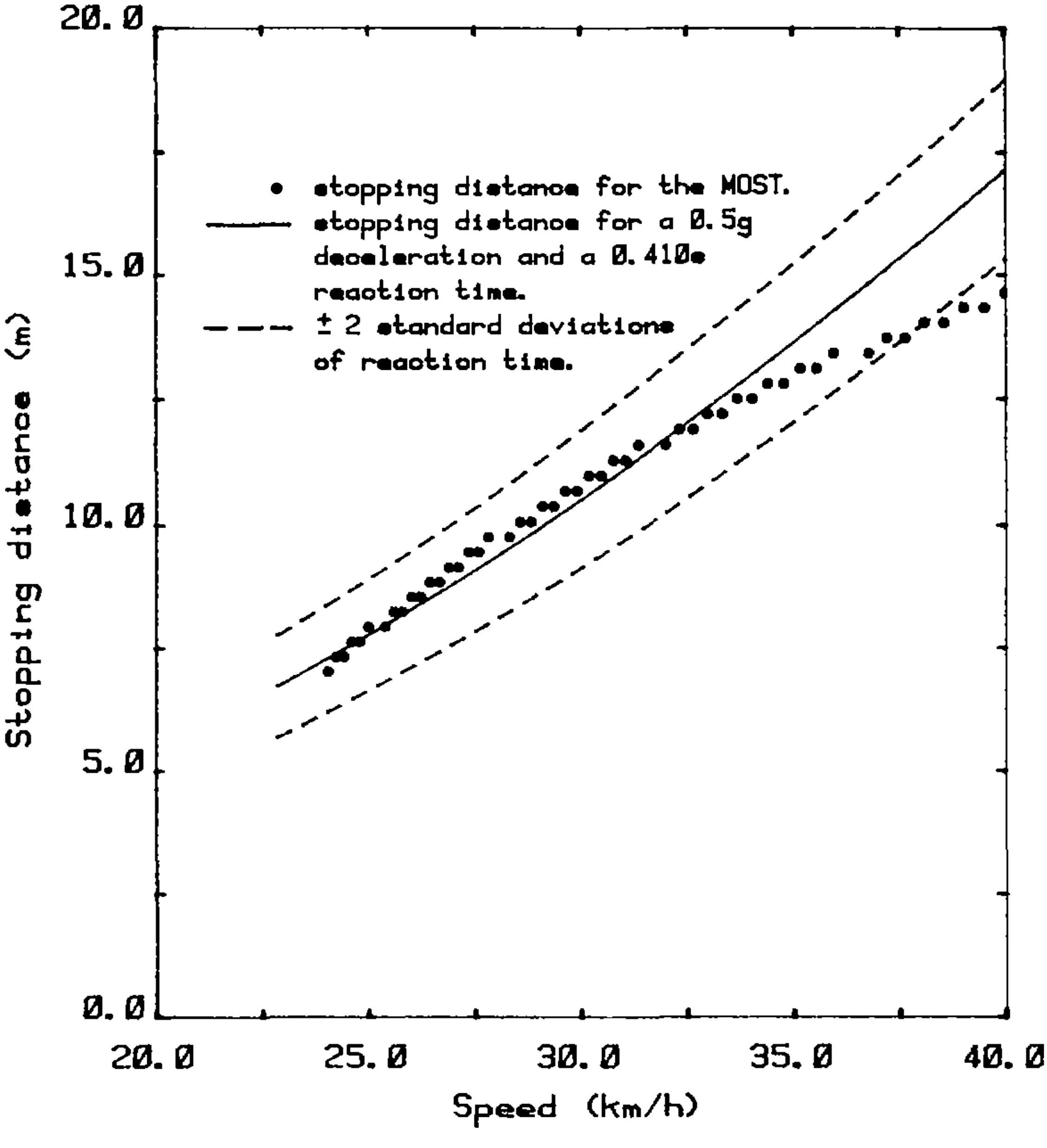

Figure 4.13 Comparison of the MOST criterion stopping distance and calculated distance for a constant deceleration level.

(ii) There appears to be a left/right asymmetry in riders: They perform better in left-hand avoidance manoeuvres than right-hand ones. This could disadvantage riders assigned a right-hand manoeuvre in the MOST.

(iii) Use of an unfamiliar motorcycle with a sensitive rear brake appears to have had a deterimental effect on emergency braking in a curve. Riders, on average, could not attain the required stopping distance for an emergency stop in a curve. Stopping distances achieved during straight line emergency braking were considerably better.

(iv) By considering the histograms of score frequency and the correlation coefficients between overall score and exercise score, the exercises which appear to be the 'best' skill discriminators are:

7, Emergency Braking: Straight
8, Obstacle Turn

(v) A comparison with work performed overseas using a less skilled group (as indicated by overall test score) showed the following exercises to discriminate between the two groups:

3, Accelerating in a Turn
6, Curve Speed Selection
7, Emergency Braking: Straight
8, Obstacle Turn

(vi) A regression analysis showed the following two variables (background factors) to be the 'best' predictors of test score: rider sex, and how many kilometres are ridden in the average week. These results are largely consistent with other studies.

(vii) The performance check used for the emergency braking exercises in the MOST is biased. Riders performing the exercises at too high or too low a speed are required to achieve significantly higher mean decelerations than riders travelling at the prescribed test speed.